Making 'waves' in physics class: a qualitative study of teacher-student dialogue in post-16 Chinese students' lessons on forces, mechanics, electricity and magnetism

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Making 'waves' in physics class: a qualitative study of teacher-student dialogue in post-16 Chinese students' lessons on forces, mechanics, electricity and magnetism

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Abstract

Based on theoretical research, this research constructs a theoretical framework for the semantic waves and semantic contexts of physics classroom discourse between post-16 students and their teachers. According to the theoretical framework, this research depicts the semantic waves of seventeen physics open classes and analyses the relationship between semantic waves and semantic contexts.

This study used qualitative data collection and analysis methods. It collected teachers' open class video materials, textbooks, curriculum standards and corresponding teaching design text materials, and conducted multiple semi-structured interviews with related teachers. The scope of the sample is concentrated on three topics of electromagnetics (magnetic phenomena and magnetic field, force in the magnetic field and electric field) in the first grade of upper-secondary school in China. This study found that teachers consider many factors when designing teaching, including three major aspects: teaching materials, students and teaching techniques. The teaching objectives, teaching content and teaching sequence contained in the textbook and curriculum standard are what teachers would follow when designing teaching. Regarding the students, teachers pay more attention to their existing knowledge, designing the review and extension of knowledge on this basis. The samples are teaching videos. For preparing the videos, teachers pay attention to the design of teaching techniques, including activities, experiments and props. In addition, teachers rehearse repeatedly to achieve smooth teaching. This repeated deliberation illustrates the use of teaching language to connect and express the design. The classroom teaching finally presented by each teacher depicts its unique semantic waves. Differences occur in the teacher's consideration of the students' status and the topic of teaching. However, these semantic waves also have similarities. From these seventeen lessons, four forms of semantic waves are found: small fluctuations, large fluctuations, flat lines and blanks. Furthermore, these waveforms have corresponding relationships with their semantic contexts. The semantic contexts have corresponding theoretical semantic waves and change with the actual situation of teaching. Interaction between the semantic contexts superimposed on each other to form the semantic waves of the teaching discourse of the whole class.

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Abbreviations

APL	Adapted primary literature
ACK	Academic content knowledge
AQA	Assessment and Qualification Alliance
CD	Classroom Discourse
CDA	Critical discourse analysis
CHC	Confucian Heritage Culture
CK	Content knowledge
CLA	Corpus-Linguistics Approach
CM	Classroom Management
CoRe	Content Representation
DA	Dispositive Analysis
DHA	Discourse-Historical Approach
DRA	Dialectical–Relational Approach
FIAS	Flanders' Interaction Analysis System
FOCUS	Foundation Corpus
IRE	teacher initiative, student response, and teacher evaluation
IRF	initiation-response-feedback
IS	Instructional Strategies
KoS	Knowledge of Students
LCT	Legitimation Code Theory
MoE	Ministry of Education of the People's Republic of China
NEEA	National Education Examinations Authority
NTCE	National Teacher Certificate Examination
OECD	Organization for Economic Co-operation and Development
PaP-eRs	Pedagogical and Professional experience Repertoires
PCK	Pedagogical content knowledge
PCKg	Pedagogical content 'knowing'
PISA	Programme for International Student Assessment
PK	Pedagogical knowledge
PSHG	Posner-Strike-Hewson-Gertzog
SAL	Students' approaches to learning
SC	Scientific concept
SD	Semantic Density
SFL	Systemic functional linguistics
SG	Semantic Gravity
SM	Scientific Method
SMK	Subject Matter Knowledge
M (F, E)	M, magnetic field and magnetic phenomena (F, the force on the current-carrying wire in the magnetic field; E, electric field strength)
TPSK	Topic-specific professional knowledge
TGG	transformational-generative grammar
TQC	teacher qualification certificate

Glossary of terms

Good Lesson	The good lesson that selected in the national project named '*Good Lesson*' (pseudonym, the project plan is shown in Appendix 2.2: Activity Plan).
Open class	An 'open' class is taught by a selected teacher on a specific topic and observed by educational experts and other teachers. Experts evaluate teachers based on a specific evaluation form (the project evaluation form is shown in Appendix 2.1: Evaluation Index of 'Good Lesson') and rank teachers' performance. Teachers usually spend more time and energy in designing an open class, including the preparation of teaching language, structure, activities and materials (for instance the various experiments and slides) (Chen, 2016; He, 2010; Ma, 2010; Wang, 2015; Wang, 2018) than their regular lessons. Even each action and expression are designed in advance (Wang, 2015).
Gaokao	Its full name is 'Nationwide Unified Examination for Admissions to General Colleges'. The Chinese college entrance examination. Students take the college entrance examination at the same time (usually on June 7th-8th every year) across China. The examination papers have eight versions for different provinces, National Examination Paper volume I, National Examination Paper volume II, National Examination Paper volume A, National Examination Paper volume B, and four provincial self-proposed examination papers (details are shown below).

The Type of National Examination Paper	Participating provinces
Volume I	Shandong, Fujian, Hubei, Jiangsu*, Guangdong, Hunan*,Hebei.
Volume II	Hainan, Liaoning*, Chongqing
Volume A	Yunnan, Guangxi, Guizhou, Sichuan*, Tibet
Volume B	Henan, Shanxi, Jiangxi*, Anhui*, Gansu, Qinghai, Inner Mongolia, Heilongjiang, Jilin*, Ningxia, Xinjiang*, Shaanxi.
Provencal self-proposed examination paper (Beijing)	Beijing
Provencal self-proposed examination paper (Tianjin)	Tianjin
Provencal self-proposed examination paper (Zhejiang)	Zhejiang*
Provencal self-proposed examination paper (Shanghai)	Shanghai

* The provinces of volunteer teachers in this study

Accredited Teaching Programme	Students who successfully graduate from the Accredited Teaching Programme can obtain a teacher qualification certificate. Accredited Teaching Programme offer general courses, subject courses, and teacher education courses by relevant national requirements. Graduates who complete the prescribed courses under the programme's training plan and meet the graduation requirements are deemed to have passed the written test of NTCE. Accredited Teaching Programme should establish the

education practice portfolio of their students with the main contents of the internship plan, the practice teaching plan, the practice summary and the assessment. The programme should accredit and confirm the education and teaching practice ability of their graduates through strict procedures which are deemed to have passed the interview of NTCE.

Statement of copyright

Acknowledgements

...Since meeting is a kind of gift given by the time. So, when you leave, you should smile and put the memories in your heart...

-Zhou

I still remember that a few years ago, I embarked on the road of studying with my curiosity about life in the UK and the desire for knowledge. A brand new country, a brand new campus, brand new friends and teachers, everything around is new. All these seem to give me new vitality and challenges and push me to embark on a new journey.

Here I would like to thank my supervisor-Professor Vanessa Kind especially. It is an honour for me to be a student of Vanessa. She guided me when I was confused and gave me the motivation to move forward when I was hesitating. During the research and thesis writing period, all the steps were completed under the meticulous guidance of Vanessa. Her rigorous attitude towards work and research will always affect and inspire me. Vanessa is more like my mother rather than a supervisor. She also takes good care of my life.

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I would like to thank my friends. We helped and encouraged each other. I also would like to thank the leaders and teachers involved in the research for providing support for my research.

Thanks to everyone who met here, thank all the friends and teachers who have helped me, thank you!

Goodbye for now
The train of this programme is approaching
On the path to the future
never to return
Just say goodbye
Do not look back even if I am reluctant to leave

I cannot find a path with neither wind nor rain
There is bound to be some loneliness and sadness
but there is also endless hope.
This journey is long but fleeting
And everything converges into a fulfilling scene in the end

Chapter 1 Introduction

...language is not just vocabulary and grammar: Language is a system of resources for making meanings. In addition to a vocabulary and a grammar, our language gives us a semantics ... The semantic resources of language are the foundation for all our efforts to communicate science and other subjects. To understand how communication works, and what makes it succeed or fail, we need to analyse how we use language to mean something.

- Lemke, 1990

There was a time when teachers were seen standing at the front of the classroom during science class, while students were sitting in their places neatly. The science teacher explained scientific facts, and the students listened and took notes. This is what I experienced in school, and is the teaching method carried out in many schools in underdeveloped areas in China. However, China's situation is changing in terms of science curriculum policy (MoE, 2001), and in many countries, this coincides with changes in science teaching practices. What should the science class look like? This question challenges researchers. This research aims to trace teachers' professional knowledge, from the perspective of linguistics, as a medium to study the presentation of teachers' classroom discourse and reconstruct the appearance of teachers' classroom discourse.

'Talk has always been one of the essential tools of teaching, and the best teachers use it with precision and flair.' (Alexander, 2008, p. 9) In classroom teaching, the transmission of knowledge is mostly achieved through classroom talk. The teacher's skill of talk determines the quality of a lesson. This study is about physics discourse in post-16 classrooms in Chinese secondary schools.

This study originates from my teaching, through which I became interested in the role classroom-based teacher-student dialogue plays in mediating student learning and teacher professional knowledge. I taught science to students from a variety of age groups and backgrounds. These experiences prompted me to think about the language of teaching. Teachers adapt their language to meet the needs of their students. Distinctions may be based on students' academic and social backgrounds, which make learners understand a concept.

As a kindergarten teacher, I taught 3-6 year olds preschool children science[1]. For example, when teaching air pressure, I usually used childlike language and tone. The discourse was as follows:

> Teacher: 'Children, look, this is a glass with some fairies in it. They can draw water out of the plate. Can you see them?' The children responded, 'No, I can't see them. Where are they? Are you sure that there are some fairies?' Teacher: 'I will do an experiment to show the existence of these fairies.'
>
> (Experiment show*)
>
> Teacher: 'What can we see?' The children responded, 'The water comes into the glass. It's amazing. Teacher, you can do magic!' Teacher: 'Now you believe what I said. In fact, these 'fairies' have a scientific name, 'air pressure'. It exists not only in the glass but also everywhere.'
>
> * The experiment is called "Magic Cup". First, pour some colourful water onto a plate and then place a burning candle in the centre of the plate. Second, place a glass over the candle. The experimental phenomena is the water in the glass will rise up.

Considering the background of the class of children, I used 'fairy' in this teaching design to raise children's learning interest. 'Fairies' are known for their miracle and cute appearance, and can be 'seen' in popular cartoon series. The kindergarten is a private organisation, meaning that the tuition fee is costly. The children are from high-income families. Most of their time is spent on learning various subjects, including in-school subjects and the 'interest classes' after school. Therefore, watching cartoons is one of their rare leisure activities. They like to watch and talk about cartoons with peers and adults. Thus, I brought the image of 'fairy' into the class language to close the distance between science and children's daily interests.

Additionally, I communicated with children from a rural place in China, where there is no television and even cartoon books in their homes, so they cannot know 'fairies' as children from urban places do. All the vivid and magnificent words would fade away in front of these children. Using life-like teaching strategies in science lessons can create a relaxed atmosphere, inspiring and cultivating interest and motivation (Cazden, 1976; Mercer, 1995; Zhu & Zhang, 2010). Thus, a teacher's teaching language needs to conform to learners' everyday talk. To illustrate, when

[1] This science course aims to teach children some simple scientific knowledge through scientific experiments and scientific phenomena in life.

teaching the same topic to 14-15 year olds, I changed my discourse style and introduced air pressure as follows:

> Teacher: ‘We live in the atmosphere around the earth. Gas, like liquids, has no definite shape, possesses mobility, and is also affected by gravity. Does it also have pressure in it like a liquid? Now is group experiment time. Each group has two straws. Please design experiments to prove that if the air pressure exists or not.' The students put the straws on their desks, books, floor, or even put the two straws together. 'After pressing the straw, it will be fixed on the desk.' 'Because there is no air in it.' 'Not exactly, there is still some air in it, look.'… The students give their views and have a good group discussion. Teacher: 'OK, time is up. Please look up and see ahead. What conclusion do you find out?' Students responded, 'Air pressure exists.' 'When the straw is pressed, the air inside is forced out. As a result, the air inside the straw becomes less, like the water, and the pressure inside becomes low. The straw is then held in position by the high pressure outside.' Teacher: 'Good! The atmosphere exerts pressure on the object that is immersed in it from all directions. This kind of pressure is called air pressure.'

In this case, more scientific language replaced childlike language. The group experiment aimed to inspire thoughts and train manipulative skills. Students can do experiments by themselves and express themselves through group discussions (Gilles & VanDmer, 1988). Group activities also support the student to proceed with assimilation, using their prior knowledge to explain the new phenomenon (Novak, 2002).

In the third example, with 16-17 year olds, I discussed air pressure in this way:

> Teacher: ‘We have already known the existence of the air pressure. What is the cause of air pressure? Considering the kinetic theory model*, air is composed of a large number of molecules. The molecules of gas are in constant, random motion and frequently collide with each other and with the walls of any container. Like we throw a basket of basketball on the wall, and then the balls will collide with each other and press the wall. Air pressure is caused by the collisions between the particles and their container.'
>
> * This model had been introduced in the previous lesson.

According to Piaget's Stage Theory of Cognitive Development, upper-secondary school students are capable of deductive and hypothetical reasoning without concrete objects (Woolfolk, Hughes, & Walkup, 2013). Discourse in such a class should be concise and authoritative. Upper-secondary school students have had exposure to academic knowledge and life experience, especially the students in this class. Most students prepare for class, including but not limited to previewing the textbook and exercises. They are from a rural village and are eager to see the outside world. There are two choices before them: studying hard and going to university in the future, or after graduation from upper-secondary school, working with their parents and staying in the village for the rest of their lives. Based on these facts, most choose to study hard to meet the college entrance examination standards. Therefore, they have good academic quality based on their test scores. These facts meant I directly used professional terminology without explanations and metaphors.

My teaching language distinguished between these three classes of students intuitively based on learners' age and the intended teaching goals. Moreover, broader knowledge of students and school features plays a part. With age, learners' level of conceptual understanding becomes deeper (Woolfolk et al., 2013), which prompts a change in teaching language. The constant is teaching language needs to be close to learners' lives. Life-like teaching language can facilitate learners associating concepts and reality, and inspire learners' conceptual change (Cazden, 1976; Mercer, 1995; Zhu & Zhang, 2010).

However, physics has physics language, which is different from the language of daily life. Physics language is logical, scientific, and mixed with many professional nouns and mathematical formulas. It is not casual. Science courses in secondary school mainly require students to understand concepts of scientific phenomena. Upper-secondary school science courses require students to accept and use physics language. Teachers need to balance between making it easy for students to understand and their mastering the physics language. This is consistent with Maton’s (2013) concept of semantic gravity and semantic density of semantic waves. Maton (2014b) proposed Legitimation Code Theory (LCT) and used the concept of semantic waves to analyse teachers' classroom discourse. Blackie (2014) studied the application of semantic waves in chemistry teaching and pointed out the importance of semantic density and semantic gravity conversion for efficient classroom construction. Semantic waves in the analysis of teachers' classroom discourse should be feasible, and could be a tool that makes teachers' use of strategies explicit. However, the existing semantic wave application is only used to explore the rules of knowledge presentation, rather than the discourse distribution of the whole class.

Teachers consider the use of language and pay attention to teachers' professional knowledge, encompassing course arrangement, the use of textbooks, and the situation of students. These factors constitute the context of classroom discourse. Therefore, this study posits that a comprehensive analysis of the common waveform and reconstruction of semantic waves in teacher classroom discourse would be beneficial for understanding its forms and principles. In this regard, I employ the term 'semantic waves' to refer specifically to a unique manifestation combining Maton's (2013) concept of semantic waves with Halliday and Martin's (1993) notion of formality as well as Bernstein's (2003a) framing. By reconstructing an analytical framework based on these concepts, it becomes possible to depict the entirety of a classroom teaching semantic wave.

1.1 Contextual background to this study

'Education' in Chinese means to 'impart knowledge and cultivate people'. The term refers to the person as well as knowledge. Pedagogy should be a person-based activity, oriented towards an individual's learning (Lin, 2016). Humans live in a society that determines their affairs are affected by themselves, and social expectations and standards (Marx, 1972; Spirkin, 1983). The communicative context of education seems essential in achieving these. This section discusses: 1) the Chinese national curriculum; 2) the present status of Chinese secondary school teacher training; 3) the variety situation of Chinese secondary classes.

1.1.1 *Chinese Physics national curriculum standard for upper-secondary school*

The Chinese education system (Appendix 3) has a highly centralised structure. Curriculum documents are established by the national institution and act as curriculum development criteria, implementation and evaluation (He & Wang, 2015). The documents include whole curriculum operative activities to guide teaching practice. In 2011, China promulgated its revised compulsory education curriculum document. In 2017, the country enacted a reform of its upper-secondary school curriculum and implemented a new college entrance examination system. As Chinese education has developed educators realise the importance of students' and teachers' literacy development. Chinese national curriculum document mentions, 'laying a solid foundation for people's lives is the aim of education' (Ministry of Education (MoE), 2017, p.1). The formulation of teaching objectives in the Chinese curriculum is based on Bloom's taxonomy of educational objectives. Bloom divided cognition into five categories, knowledge, comprehension, application, analysis, synthesis, and evaluation; each level has an appropriate expression verb list (Krathwohl, 1964). Furthermore, the taxonomy of teaching objectives corresponds to the difficulty and quantity of related knowledge points that appeared in the unified examination.

The physics curriculum is a foundation course in Chinese secondary schools. It is intended to implement the fundamental task of cultivating people, further enhance the core literacy of students in physics, lay the foundation for the life-long development of students, and promote the inheritance of human science and society development (MoE, 2017b). Physics is a basic subject of natural science, which studies the basic structure, interaction, and movement laws of matter in nature. Physics is based on observations, experiments, constructing physics models, applying mathematics and other tools, and forming systematic research methods and theoretical systems through scientific reasoning and argumentation (Winter & Hardman, 2021). Teaching practice is based on curriculum documents, may react to curriculum and promote its reform (Kelly, 2009). The national curriculum document is a guideline for students, teachers and schools to practise physics education.

However, teaching practices do not fully coincide with the national curriculum document (Chen, 2015; Li, 2012). This is associated with three influential factors: curriculum document itself, teaching environment of each school and assessment (Li, 2012). These factors reflect the problem of teacher training, regional diversity and assessment. The national curriculum standards are the basis for the compilation of textbooks, teaching, evaluation, and examination, and the basis for national management and evaluation of the curriculum (MoE, 2001). This is a national regulation, and teachers have the authority to modify and adjust their teaching. However, the main authority lies in the choice of the teacher's teaching method, teaching style and teaching language. Strengthening teachers' understanding of curriculum documents, school-based curricula and updated assessment is needed to help them arrange their classroom discourse and professional development.

1.1.2 *Chinese secondary school teacher training*

Obtaining a teacher qualification certificate (TQC) is an entry threshold to becoming a teacher. In China, there are two routes to TQC: via National Teacher Certificate Examination (NTCE) or academic education (shown in Figure 1.1). The qualification examination aims to test whether the applicant has professional ethics, basic literacy, educating and teaching ability and professional development potential (The National Education Examinations Authority, NEEA, 2011). NEEA hopes to strictly control teacher career admission and select the best candidates who are willing to teach and suitable for teaching (NEEA, 2011). Finishing an accredited teaching programme is the other route to getting a qualified teacher certification. An Accredited Teaching Programme offers general courses, subject courses, and teacher education courses. Graduates who complete the prescribed courses under the programme’s training plan and meet the graduation requirements are deemed to have passed the written test of NTCE. Accredited Teaching Programme also establishes students' teaching practice portfolio, including their teaching plans, teaching performance, practicum evaluations, and other records related to teaching. The student's profile is identified as qualified, which is equivalent to passing the interview of NTCE (MoE, 2017a).

In-service teacher training in China continues the basic form of pre-service teacher training, mainly in the form of lectures and lesson study. It makes teachers who participate in the training only passively accept knowledge, and difficult to obtain real practical experience (Chen, 2014). Additionally, it cannot be overlooked that some training forms such as distance education and seminars are starting to gain attention (Chen, 2014).

The institutions that undertake pre-service teacher training are uneven in quality. It is difficult for colleges and universities to ensure the quality of pre-service teacher training under the supervision of MoE (Song & Zhou, 2015). Social training institutions lack accreditation criteria and supervision (Song, Tian, & Wu, 2020). Recruitment in an examination form ensures reliability, however, it is difficult to achieve high validity and discrimination (Li, 2020). NTCE employs examination-based selection methods, which may present similar challenges to those encountered in recruitment processes. Therefore, to improve the professional skills of teachers, in-service teacher training is significant.

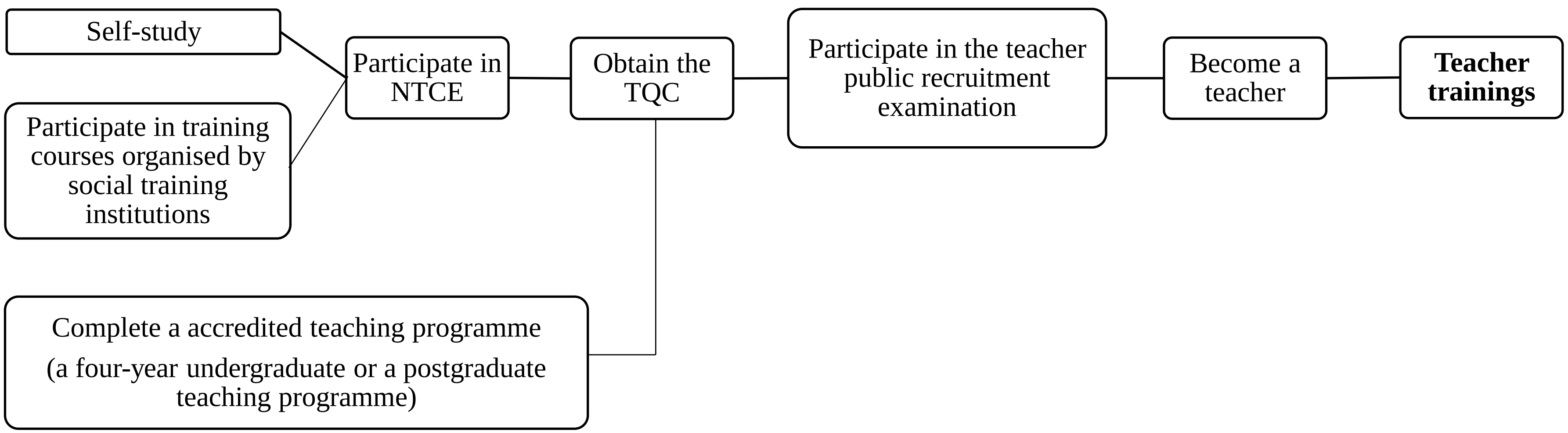

Figure 1.1 The routes to get a teacher qualification certificate (TQC) in China

1.1.3 *Chinese secondary school classes and social background*

The teachers and classes in this study are from the top 5% of schools in various provinces. In today's China, 'focus only on scores' evaluation still exists. ‘Score-only’ evaluation is a kind of activity that pays attention to paper-and-pencil test scores characterised by scores and uses these as the sole criterion to judge students, teachers and even the entire educational system (Liu & Xu, 2020). Scores are the fundamental characteristic of the examination and enrolment system of the upper secondary school entrance (called ‘Zhongkao’) and college entrance examinations (called ‘Gaokao’). The score is especially emphasised by Gaokao. The 'score only' evaluation uses Gaokao to penetrate all aspects of basic education and forms the persistent and 'specific' characteristic of basic education (Liu & Xu, 2020).

Since the current mainstream status of educational evaluation in China is based on various examinations, scores become the primary measure of education outcome. Although the new curriculum reform and social media advocate people's all-round development and personalised development, reliance on scores is a social problem that requires time to change. Zhang (2019) suggested that because of 'fairness first' rather than 'validity first' if the test score is not the primary criterion for admission, it is likely to endanger the fair competition mechanism, meaning lower social class children families will be marginalised. Furthermore, position, capital and other interests in a specific field forced the use of 'score-only' evaluations.

In the field theory, '[t]*hose in dominant positions operate essentially defensive strategies, designed to perpetuate the status quo by maintaining themselves and the principles on which their dominance is based*' (Bourdieu, 1993, p. 83). Bourdieu's statement functions to provide a critical sociological lens through which the persistence and implications of the ‘score-only’ evaluation system can be understood, highlighting its role in maintaining social hierarchies and inequities. Bourdieu's statement in the passage serves to provide a theoretical framework for understanding the persistence of the ‘score-only’ evaluation system in China’s educational context. Specifically, it helps to explain the underlying social dynamics and power relations that sustain this system. Bourdieu’s concept of ‘defensive strategies’ by those in dominant positions is used to frame the reliance on ‘score-only’ evaluations as a deliberate tactic by policymakers and other stakeholders in positions of power. The maintenance of the status quo through score-based evaluations is not merely incidental but a strategic move to preserve existing power structures for policy makers.

In school education and admission examinations, students obtain specific academic positions and admission capital through scores. The competition of position and capital continuously strengthens the significance of scores. 'Score-only' evaluation seems objective and fair; however, it may conceal or exacerbate inequity that regions and groups have in terms of access to higher education. This fairness reduces violations in the enrolment process but hurts most students' abilities and personality development (Tian & Liu, 2010).

Moreover, 'score only' is pursuing absolute fairness with the supremacy of scores, rather than substantive fairness that is conducive to the reasonable development of human beings (Dong & Li, 2019). Despite this, Chinese people have not yet found a better alternative to standard tests, the evaluation that maintains social order and equity. The pursuit of absolute social justice leads to a 'score-only' evaluation existing in Chinese society.

In the context of the massive population[2] of China, if the government invests the same amount in every school, each school will receive very little funding. Key schools[3] emerge, which receive enhanced financial support from local government and better social status. The evaluation standard of the key school is based on Gaokao scores of graduates. Therefore, ranking on Gaokao scores has become an essential criterion for parents and students to choose schools, and an essential condition for schools to receive government funding (Zhang, 2019). A top school that has a higher ranking indicates adequate teacher-student resources and sufficient government funds.

The large class size could be a chief symbol of Chinese school classes. Typically class sizes in Chinese secondary schools are around 50, while in some rural schools, this may exceed 70. Bourke (1986) suggests that smaller class sizes help teachers pay more attention to their instruction instead of class management and lead to high learner outcomes. The Large class size leads to 'cramming' teaching that educators criticise. Researchers think that rote-learning and passive attitudes to learning target low cognitive goals (Kember, 2000). However, there is a paradox. Beijing-Shanghai-Jiangsu-Zhejiang (China) students performed better in PISA 2018 (Organisation for Economic Co-operation and Development, OECD, 2019) than most other students. Under Confucian heritage culture (CHC), students adapt to large classes, and teachers carry out meaningful learning within whole-class interaction (Biggs, 1998). Additionally, students participating in the test are all from top schools in developed cities in China. Thus, Chinese basic education in these areas could be effective.

1.1.4 *Chinese open class*

A national project named 'Good Lesson' (pseudonym, the project plan is shown in Appendix 2.2: Activity Plan), containing many 'Good Lessons' taught by various 'Good Teachers' came to the attention of this study. This project evaluated (the evaluation form is shown in Appendix 2.1: Evaluation Index of 'Good Lesson') and selected Good Lessons from the lessons submitted

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[2] There are 13737 upper secondary schools with 23753709 enrolment students in China (MoE, 2019a, 2019b)

[3] In most part of China, secondary schools are generally rated as key schools and ordinary schools.

voluntarily on the national platform (MoE, 2019c). As mentioned in section 1.1.2, lesson study is one of the main forms of in-service teacher training. Participating in and observing 'Good Lesson' is an essential part of lesson study and taken as content to promote teachers' professional development (MoE, 2019c). As the evaluation plan requests, Good Lessons are appropriate for meeting the curriculum standard requirements. Each ‘Good Lesson’ focuses on language, teaching materials and structure. Good Lessons provide a useful resource for in-service teacher training and data for researchers (MoE, 2019c).

This project is rooted in the background of Chinese ‘open classes’. An open class presents in the Chinese educational system as a tool for teacher evaluation and training (Du, 2016; Wang, 2015). The open class’s form is that educational experts and other teachers sit in the class and listen to a selected teacher teaching a specific topic. The experts evaluate the teacher, giving a rating among other teachers simultaneously giving an open class. Teachers usually spend significant time and energy preparing for an open class, including the preparation of teaching language, structure, activities and materials (for instance experiments and slides) (Chen, 2016; He, 2010; Ma, 2010; Wang, 2015; Wang, 2018) compared to normal lessons. Even each action and expression are designed in advance (Wang, 2015). The 'official' language, ‘plentiful’ activities and ‘beautiful’ slides are bonuses in the evaluation, and can influence teaching careers (Ma, 2010). The 'official' language contains two meanings. One is that teachers should use Mandarin instead of dialect, and the other is that the language is professional instead of casual and meaningless words. Open classes help instructors refine specific content, develop materials for teacher training and serve as role models for subject teaching.

Undeniably, large numbers of high-quality openly accessible classes act as teaching resources. However, open classes bring many deficiencies. Because they involve teacher evaluation, teachers spend too much time on a specific teaching process (Wang, 2015). Elaborating on one topic is necessary; nevertheless, only spending time on one or two topics hinder the term teaching process (Fang, 2016). Chen (2016) states that students would consume time in open classes to express themselves, for instance, reviewing knowledge in advance and searching for relevant information on the Internet. Open classes face overuse and over-reliance on technology, making open classes flashy (Fang, 2016; Wang, 2015; Wang, 2018). Open classes are filled with teaching activities, but lack time for students to think (Wang, 2015). Students become classroom tools. They only need to give standard answers mechanically without thinking (Wang, 2015; Wang, 2018; Zhang, 2016). Open classes supply scattered teaching resources for teachers to prepare lessons instead of being applied to daily lessons directly. It is questionable whether such a perfect classroom represents exemplary teaching.

These criticisms should not overshadow the value of open classes. Open class and the daily lesson tend to merge (Du, 2016; He, 2010). Along with the education reform, the evaluation criteria for open class have also changed. The normalized performance of teaching has become a criterion for evaluating open classes. Open classes emphasise selection of teaching purposes, flexible and open teaching methods with a focus on students' study guidance (Chen, 2012; He, 2010; Lan, 2019). Based on existing teaching plans, teachers refine their language, re-design teaching activities, improve teaching efficiency, and strive to make each lesson an ‘open class’. Students are encouraged to improve their enthusiasm for learning, to prepare in advance for each lesson and be active learners (He, 2010). The national project ‘Good Lesson’ brought together the ‘good’ open classes in China and provided teachers with high-quality teaching resources, optimised teaching designs and thoughtful teaching skills (Du, 2016; MoE, 2019c). Good Lesson resources offer a standard corpus and high-quality resource base for teaching. Good Lesson is a representative sample for this research to reveal how teachers teach specific physics topics.

1.2 The aim of this study

This study focuses on teaching physics conceptual knowledge to post-16 students via Chinese open classes. Implications arise for teaching scientific knowledge using dialogue that promotes science learning in post-16 students.

Enhancing the capacity of teachers is essential to smooth implementation of science education reforms. In China, teachers are required to combine scientific practice with core literacy and cross-domain concepts while teaching (MoE, 2017b, 2019d). Considering the key role that teachers play in implementing educational reform, understanding how teachers convey knowledge in the classroom is essential. However, little is known about how Chinese teachers organise classroom discourse, the primary tool used to convey knowledge. This point is overlooked in research on improvement of educational practice. Guidance to teachers should be general policy training, attending to the needs of teachers' teaching and supporting teachers (Dong, Zhou, & Cui, 2017). In addition, few studies exist exploring the relationships between teachers' professional knowledge and their classroom discourse (Song, 2016). This research studies teachers' teaching characteristics, including pedagogical content knowledge (PCK) (Shulman, 1987) and discourse to resolve these gaps in literature and become a unique introduction to Chinese physics teachers' teaching discourse. Relationships within collected materials are examined for links between individual teachers' characteristics and teacher discourse. The teacher is not a passive transferor of knowledge, or an executor of curriculum plans, but an active adaptor, researcher and creator (Jin & Zhang, 2019). This research hopes to provide reference points for teachers' self-adjustment and research.

As outlined above, this study analyses how Chinese physics teachers make meaning in post-16 physics classrooms through discourse analysis and attempts to find theoretical explanations and interrelationships. Considering that the science studied is physics, from a physics point of view, all matter in the world has wave-particle duality, and waves are essential matter. We use waves to obtain information. For example, our eyes receive light waves, our ears receive sound waves, and the human brain can precisely perform Fourier processing of these signals from early on in our lives. This research treats physics classroom discourse as a wave, and uses Fourier's ideas to transform it. Therefore, physics classroom discourse can be visualized and understood by physics teachers.

Based on the researcher’s teaching experience, the current situation of Chinese education and existing literature, the research questions of this study are as follows:

1. What is the semantic context of post-16 Chinese students' physics lessons?

The semantic context of post-16 Chinese students' physics lessons is physics class. This research involves three data sources. Firstly, it analyses information that teachers need to convey by analysing reference material, that is, a textbook. In China, textbooks and curriculum standards are mandatory for teachers (mainly due to Gaokao Baton, see section 1.1). Information conveyed by textbooks becomes content that affects teachers’ teaching. For better analysis of text content, a comparison method is adopted. Analysis of 'AQA Physics: A Level' (AQA stands for Assessment and Qualification Alliance) (Breithaupt, 2015) is analysed as a horizontal comparison. The vertical comparison mainly compares 'Physics: Year nine' (Peng, Q., 2013) and 'Physics: Elective course 3-1' (Zhang, 2007) in China. The purpose of the comparison is to emphasise similarities and differences (Newby, 2014). Similarities represent the same knowledge transfer process in both textbooks, while differences imply different concerns.

Secondly, starting from teachers, through analysis of teaching design and teacher interviews, this study investigates the content teachers consciously consider during their preparation process for their open class. The interview offers valuable insights into the present state of physics education, emphasizing the practical challenges encountered during its implementation, and providing significant recommendations for addressing these issues from teachers’ standpoint. This provides priori sources for subsequent analysis of teachers’ classroom discourse.

Thirdly, video material serves as a visual data source that dynamically illustrates the real-time interaction between semantic contexts and semantic waves.

The theoretical framework conducted in the analysis of the classroom context solely focuses on Halliday and Martin's (1993) notion of formality, Bernstein's (2003a) framing theory and pedagogical content knowledge (PCK) (Kind & Chan, 2019), overlooking the semantic waves present in textbooks, teaching design, and teacher interviews. To comprehensively investigate the evolution of classroom teaching discourse over time, it is crucial to consider these contextual elements as they serve as preparatory tools and aids for teachers' instruction, however, it should be acknowledged that teachers' teaching do not adhere strictly to these. Consequently, an analysis of the classroom context encompass formality (Halliday & Martin, 1993), framing (Bernstein, 2003a), and pedagogical content knowledge (PCK) (Kind & Chan, 2019) without describing semantic context's semantic wave.

1.1 What are the scientific concepts and methods involved in the specific topic?

1.2 What are the students' situation that influences teaching?

1.3 What factors that influence instructional practices?

1.4 How do teachers handle these factors within teaching?

2. What is the visual representation of teacher discourse's semantic waves in post-16 Chinese students' lessons on forces, mechanics, electricity and magnetism?

This study utilizes the theoretical analysis framework of classroom discourse, as established in existing literature, to depict semantic waves of classroom discourse. Through successful transformation into a visual waveform, this research examines the characteristics of sample classroom discourse semantic waves and compares patterns between different teachers and topics to identify similarities and differences.

2.1 What are the common waveforms of semantic waves?

2.2 What is the significance conveyed by these common waveforms?

2.3 How could linguistic expressions be converted into waveforms?

3. What is the relationship between the semantic waves of post-16 Chinese students' lessons discourse and semantic context?

This research compares the semantic waves with their semantic context to analyse the relationships, summarise the rules, and trying to make corresponding explanations.

1.3 Thesis structure

This thesis is composed of seven chapters, shown as follows:

Chapter One explains the background and purpose to the research and discusses research questions.

Chapter Two is a literature review, which summarises current research in classroom discourse and the chosen framework for teachers' professional knowledge. Then constructs the analytical framework for this research gradually.

Chapters Three describes the research methods, introduces analysis process, then describes the construct of the teacher's classroom discourse semantic waves and semantic context framework.

Chapter Four studies the central basis resource (textbook) and teaching design of teachers' classroom teaching, and further revises the semantic context framework involved in teachers' classroom teaching.

Chapter Five mainly analyses the common waveform types and distribution characteristics of the semantic waves of the teacher's classroom discourse in the samples, semantic amplitude and construction resources of semantic waves. After construction of semantic waves, this chapter deconstructed the waves based on the relationship between semantic waves and context.

Chapter Six is the conclusion of this thesis. Based on the research in Chapters Three to Five, Chapter Six summarises the research purpose and research questions of this research, explores the waveform characteristics and construction resources of semantic waves, and proposes research inspirations beneficial to teaching practice. Limitations and the improvement direction for follow-up research are discussed.

Chapter 2 Literature Review

'[T]o discover some essential common features, hidden beneath a surface of external differences, to form, on this basis, a new successful theory, is important creative work.' (Einstein & Infeld, 1938)

2.1 Introduction

This chapter reviews relevant studies about classroom discourse. Section 2.2 discusses research on discourse analysis that includes research of words (section 2.2.1), discourse structure (section 2.2.2), and the dialectical relationship between discourse and society (section 2.2.3), hence building the theoretical basis in linguistics for this research (section 2.2.4). Linguistics provides diverse and detailed research tools for classroom teaching research. However, Hymes and Farr (1982, p. 14) stated that '[p]rogress in linguistics is not always pay-off in pedagogy', '[i]f education, then, is going to have the insight into classroom discourse that it needs and deserves, it cannot wait upon the progress of linguistics and the social sciences'. Since the topic of this research is science classroom teaching, section 2.3 focuses on discourse in science education that tends to sort out how science classroom are analysed in the existing literature. Section 2.4 concerns the context of classroom discourse and emphasises pedagogical content knowledge as the probe to investigate teachers' professional knowledge.

2.2 Research theories on discourse analysis

Discourse is the core concept in discourse research and is the most ambiguous. Initially, discourse was associated with linguistics as a synonym for language or text (Chalaby, 1998). Discourse represents words, and does not include other meanings. Harris (1963) recommends describing discourse as material constituted by uncovering equivalent formal units and structures. Chomsky proposed 'transformations', draws inspiration from Harris's notion of transformation and builds up a theory of transformational-generative grammar (TGG) to explain human talk and human understanding of new sentences. TGG considers that discourse abides by sentence structures which feature formal grammar (Coulthard, 1985). Harris (1951) views transformation as the equivalence relation among sentences or formal units and structures, and Chomsky's transformation is the equivalence relation between different structures within a unit (or a sentence). This difference is conceptual, whether it is a dependency among sentences or sentences and units, or a dependency between structures within a unit or a sentence. Gee (2014, p. 29) identified the term 'discourse' as '[the] *ways of combining and integrating language, actions, interactions, ways* *of thinking, believing, valuing, and using various symbols, tools, and objects to enact a particular sort of socially recognisable identity*'. The connotation of discourse is experienced from focusing on words, syntactic structures to an amalgam, a complex of the various channels that convey information along with the language. This expansion of definition brings together linguistics and its context, which makes it possible to comprehensively de-structure and reconstruct discourse in a real situation. The purpose of this research is to de-structure and reconstruct discourse in physics classroom teaching through analysis of teachers' discourse and its context which conforms to the connotation of discourse.

With the enrichment of discourse connotation, discourse analysis becomes complex. Researchers must solve the problem of how to carry out feasible and effective discourse analysis. Discourse analysis involves more and more fields, and the accompanying rules are more and more complicated. An increasingly broad set of rules makes for good description but reduces interpretation feasibility (Halliday, Hasan, Halliday, Christian, Matthiessen, & Matthiessen, 2009). Halliday's systematic-functional grammar (SFG) attaches importance to sociological aspects of language (Halliday et al., 2009). The constituents of discourse are required to meet the demands of an interactive context. Although Halliday's ideas were influenced by sociologists, such as Bernstein, which made the interpersonal process an essential part of linguistic theory, Halliday states that grammar analysis should be the first step of analysis of text (Halliday & Matthiessen, 2004). This means that linguistic approaches aim to reveal linguistic structures, not communicative processes, such as how language is organised in a sentence (Christie, 2005). This study is a study of discourse, and it is necessary to understand the study of words and linguistic structures. However, as the research object is classroom discourse, this specific semantic context needs to refer to research on classroom teaching.

Sociologists and philosophers concerned with communicative contexts in which discourse is a resource describe conversations and meaning behind the language used by a community. A discourse community is a group holding common knowledge (Edwards & Mercer, 1987). For instance, when teachers discuss with each other, they use educational language. Sociologists typically use 'power' to analyse discourse. Bernstein's sociolinguistic coding system (Bernstein, 1990a) offers a framework for analysing teaching and learning through classroom interactions. Bernstein (2003b) points out that many school teachers come from the middle class of society. Their formal linguistic coding system is thus the primary coding system in schools and middle-class families (Bernstein, 2003b). For middle-class students, their family language is consistent with their teachers' language. As a result, students from middle class understand and participate in teacher discourse more readily compared to working-class students. For students from working families, due to they are not accustomed to discourse system in classroom teaching, the content of teacher's teaching would be difficult and tedious to them, which does not serve the purpose of classroom teaching. This suggests the invisible influence of discourse context on teaching. Therefore, the analysis of the discourse contexts in teaching is necessary and needs the attention of teachers.

The following part of this section discusses the related research about the words, syntactic structures and implied relationships in more detail.

2.2.1 *Corpus Linguistics*

A corpus is a collection of oral or written texts used for linguistic analysis based on a design standard affected by the intended purpose and scope of the corpus itself (Weisser, 2016). The Corpus-Linguistics Approach (CLA) is a quantitative method revealing the generation of discourse from frequency lists and statistics (Wodak & Meyer, 2016). CLA uses computer-aided indexer software to analyse large amounts of text data. Due to the complexity of language and discourse usage, establishing an accurate relationship between discourse and its meaning can be difficult. Commonly used methods of discourse analysis rely heavily on the sensitivity of the analyst's dialogue and situation. Therefore, traditional discourse analysis methods are questioned: interpretation of dialogues varies (Potter & Wetherell, 1987). The corpus method responds to this criticism.

Limited research in science classroom discourse applies corpus linguistics. For example, Haglund, Jeppsson, and Ahrenberg (2015) stated that corpus linguistics is an accessible approach to studying languages in various disciplines. These authors compared the use of momentum, in English and Swedish in Europarl[4] and the British National Corpus (BNC)[5]. They found that this physics term appears in many domains outside physics with similar meaning. They investigated occurrences of momentum in Korp. The metaphorical use of momentum in Swedish was found to have an increasing trend in many domains (Haglund et al., 2015). Rees (2017) constructed a chemistry corpus, Foundation Corpus (FOCUS), for British Foundation programme (Year 0) students and integrated this into chemistry teaching. Rees (2017) developed a chemical language diagnostic test (CLDT) based on the foundation chemistry course to measure students' understanding of chemical language. He found that students' CLDT scores were strongly correlated with their chemistry test scores, indicating the importance of chemistry language in chemistry learning (Rees, 2017).

[4] A text corpus from the European Parliament (Brunt & Brunt, 2013)
[5] A Swedish text corpus, including language from daily journals, magazines, blogs, etc (Burnard, 2007)

The corpus application provides a new way of thinking for classroom discourse research and fills in gaps caused by intuition and introspective research in linguistics. However, corpus linguistics has shortcomings: loose language fragments provided by the corpus lack the integrity of context. Construction of the corpus may also bring researchers' ideological bias. Utilising the perspective of words would be a way to deconstruct discourse and get statistical data, but would not generate a complete picture. Rees (2017) proved the importance of language in science education. Teachers need to pay attention to the interpretation of scientific terms, which needs to be an important part of the analysis of this research.

2.2.2 *Systemic functional linguistics (SFL)*

Halliday's description, '[L]*anguage is the essential condition of knowing, the process by which experience becomes knowledge*' (Halliday, 1993, p. 94). SFL can help teachers understand using domain-specific language to make meaning (Hodgson-Drysdale, 2014; Schleppegrell, 2004). Halliday assimilated the functionalism linguistic views of the Prague School, Firth's systematic thought of the London School, Malinowski's contextual thoughts, and Bernstein's code theory (Flowerdew, 2017). Halliday(2004) bridges language and society (social needs, social structure, and social and cultural background). He considers all aspects of social culture to constitute the meaning-building of social reality, that is, constitute a general semiotics system (Halliday & Matthiessen, 2004).

Halliday summarised language functions into three abstract meta-functions in the process of constructing systematic functional grammar, which analyse the same sentence from three different angles. The meta-functions are ideational, interpersonal, and textual (Halliday & Matthiessen, 2004). The three aspects are complementary and form the overall meaning.

The ideational function concept indicates that language reflects language users' perceptions and responses to the subjective and objective world. In functional grammar, clauses express these concepts through transitivity[6]. Three components of transitivity analysis are participants, processes, and the environment. Process is a core component of the transitivity system. Transitivity understands experience as six operable process categories: material, mental, relational, verbal, existential and behavioural (Halliday & Matthiessen, 2004). Among them, existential, verbal and behavioural processes are the intermediates, respectively, for existing, saying and behaving.

[6] The most profound thing about our experience is that it contains various events - happenings, doings, perceptions, meanings, saying and being. All these matters are classified in the clause grammar. Therefore, a clause is not only a mode of behaviour, a mode of giving and requesting objects, services, and information, but also a mode of reflection, a mode of continual change and the flow of events. The grammar system to achieve this is *transitivity*. (Halliday & Matthiessen, 2004)

Researchers have used SFL productively as an analysis tool to study discourse in science education. For example, Thörne and Gericke (2014) investigate four Swedish biology teachers' inclusion of proteins in their Grade 9 students (15–16 years old). They analysed clauses containing protein and surrounding words semantically related to protein based on SFL analysis, and investigated the way of four teachers' explanations of proteins in their genetics teaching sequences based on the process categories. They suggested that the limitation of teaching leads to students' understanding problem of proteins as an intermediate link between gene and trait. Danielsson (2016) drew on different symbolic resources teachers utilize when introducing atoms into Swedish secondary school chemistry classrooms (students aged 14-15 years old). This study revealed that teachers used specific patterns of language when teaching specific aspects of atoms.

Seah (2020) analysed the types of errors that students used in learning the human circulatory system in Singapore's English-speaking classes. This study analysed seventy students (grade 9, age 15) across four classes using tools adapted from the SFL framework. The analysis revealed six problems in language use, the most prominent of the six is the use of participants which indicates that students need to understand the rationale for distinguishing terminology that appeared in this topic. Seah (2016) analysed grammar used when students (grade 4, age 10) expressed a topic, the life cycle of plants, which marked the students' understanding of knowledge. This study revealed that students encountered difficulties in constructing written scientific explanations and teachers did not emphasize this ability in their teaching process. She suggested that when researching conceptual development, teachers should focus on knowledge, apply scientific language adroitly (Seah, 2016). Hodgson-Drysdale (2014) reported that language instruction teaching activities (discussion, creating models and writing) improved students' language and content knowledge expressed through their writing samples. This small-scale study was part of a three-year action research project in North-Eastern United States. Seven classroom teaching observations, and written texts from seven students were collected and analysed based on SFL theory.

These studies applied SFL theory, and analysed clauses and sentences containing keywords in teachers' teaching and students' writing samples. They demonstrate it is feasible to study science classrooms through language. Explanations of scientific terminology in teaching help students to understand scientific concepts. However, SFL analysis pays more attention to grammar analysis than concerns the relationship between language and its contexts (Halliday & Matthiessen, 2004). This study applies SFL theory to analyse units and sentences, and these pieces will comprise the description of the entire discourse.

2.2.3 *Critical discourse analysis (CDA)*

Critical Discourse Analysis (CDA), also known as Critical Discourse Studies (CDS), was formerly known as Critical Linguistics (Fowler, Hodge, Kress, & Trew, 1979). The emergence and development of CDA occurred in sociology, philosophy and linguistics (Wodak & Meyer, 2016). The main philosophical basis for CDA can be traced back to the critical theory of neo-Marxism and Frankfurt School (Wodak & Meyer, 2016) which is used in political economy, therefore, discourse generation expresses ideological interests, social structures and movements in sociology, philosophy and linguistics. In addition, Habermas (1971, 1973) argues critical science must focus on the relationship between language and social communication, which also impacts CDA. Compared with traditional discourse analysis, CDA links discourse with social power to reveal social problems and propose corresponding strategies for improving them (Fairclough, 2010). CDA mainly studies not what language is, but why language is so; it is not interested in the meaning of discourse itself, but in how discourse produces meaning (Fairclough, 2013). CDA '*needs to be reflexive and self-critical about its own institutional position and all that goes with it: how it conducts research, how it envisages the objectives and outcomes of research, what relationships researchers have to the people whose social lives they are analysing, even what sort of language books and papers are written in*' (Chouliaraki & Fairclough, 2007, p. 9).

CDA is not a unified theory but a common research perspective. Therefore, the research methods in CDA are diverse. For example (Table 2.1), the Discourse-Historical Approach (DHA) (Wodak, 2001) starts with actual social problems and then proceeds to discourse analysis. DHA concentrates on setting up conceptual frameworks for political problems. The techniques of corpus linguistics are also introduced via DHA. The Dialectical–Relational Approach (DRA) combines discourse-oriented discourse analysis with social-oriented discourse analysis. DRA proposes three analysis dimensions of CDA, namely discourse, process and social (Fairclough, 2017). A three-tiered framework outlined by Fairclough is widespread in CDA (Rogers, Malancharuvil-Berkes, Mosley, Hui, & Joseph, 2005). The framework includes analysing text, discourse and social practice (Fairclough, 2010). This framework states that, first, discourse analysis should describe the relationship between specific text, discourse, and social practice by describing grammatical resources that make up this relationship (Fairclough, 2010). Next, a second goal is to explain the configuration of discourse practice (Fairclough, 2010). Thirdly, descriptions and explanations are used to explain why and how social practices are structured, changed, and transformed (Fairclough, 2010). A third approach, the socio-cognitive approach proposes that the interaction between discourse and social situation is realized through cognition. van Dijk (2008, p. 128) argues that '*context controls discourse by virtue of the definition of context as the definition of the relevant* *aspects of the social situation*'.

Table 2.1 A comparison of mainstream CDA research approaches

CDA approaches	Research path
Discourse-Historical Approach (DHA) (Wodak, 2001)	social problems ⟷ discourse analysis
Dialectical–Relational Approach (DRA) (Fairclough, 2017)	discourse analysis ⟷ social problems
A sociocognitive approach (van Dijk, 2008)	social cognition discourse structure ⤢ ⤡ social situations

CDA focuses on social issues, particularly the abuse of social power, domination, inequality, and discrimination. CDA emphasises the dialectical relationship between discourse and society, that is, social practice shapes and influences discourse, and discourse simultaneously constitutes social practice (Wodak & Meyer, 2016). The dialectical methodology is reflected in different research approaches.

The discourse within a society is shaped by social practices, encompassing the dynamics of interaction, held values, power structures, and historical context. For instance, the language employed in political debates reflects prevailing ideologies and power struggles. Similarly, language used in various social contexts such as education, religion, or media is influenced by the norms and values inherent to those contexts.

The construction of discourse is integral to the formation of social practice, concurrently playing a pivotal role in its configuration. The framing of issues, prevailing narratives in public discourse, and the ascribed meanings to specific words or symbols have the potential to impact individual and collective behaviours within society. For example, the depiction of certain groups in media or the rhetoric employed by political leaders can sway public opinion and mould societal attitudes and conduct.

This relationship is dialectical, signifying a continuous process of interaction and mutual influence between discourse and society. Alterations in discourse have the potential to result in changes in social practice, while changes in social practice can lead to alterations in discourse. This dynamic interplay shapes the culture, politics, and identity of a society over time.

This study aims to research the interweaving relationship between language and science classroom teaching through investigating classroom discourse, which conforms to Fairclough's research path, studying the phenomena in physics classroom from discourse. Methodologically, the three-tiered framework outlined by Fairclough is employed in this study. This study collects text, discourse and classroom teaching data, analyses and explain classroom teaching through discourse analysis, and finally describes and reconstructs physics classroom teaching.

2.2.4 *Summary and enlightenment*

The above review on discourse analysis theories covers words, discourse structure, and dialectical relationships between discourse and society. This study is committed to reconstructing the classroom discourse rather than deconstructing it, which requires a synthesis of various theoretical studies.

Discourse analysis needs to collect text, discourse and social practice data to describe the relationship and configuration between and within them, and dig deep into their operating mechanism (Fairclough, 2010).

This study refers to the notion of *formality* (Halliday & Martin, 1993) and *framing* (Bernstein, 2003a). The language used in science is different from everyday language. It is a specialised language formality that contains specialised terminology, notation, and special grammar. This kind of formality is not an external feature of science, but an internal feature that constitutes the construction of scientific discourse (Halliday & Martin, 1993). As Koulaidis, Dimopoulos, and Sklaveniti (2002) mentioned the basic manifestation of the particularity of scientific language formality is:

1. Specialised *terminology and notation*. It could be classified into terms, symbols and formulas;

2. *Nominalisation*. The nominalised expression could be easy to facilitate with the taxonomy of concepts, express complex information concisely and form novel conceptual entities;

3. The use of *passive voice*. A large number of passive voices representing the objective and non-personal characteristics of scientific knowledge are used to reflect the objectivity of scientific discourse.

4. *Syntactic complexity*. Complex sentences could express the logical relationship in scientific discourse and interpret scientific discourse more rigorously and comprehensively.

Table 2.2 The formality markers and value of scientific discourse

Formality markers	Formality value (from high to low)
Terminology and notation	Terms, symbols and equations; Two elements Only one element
Nominalisations	Existence of nominal groups of three or more nouns; Existence of nominal groups of two or fewer nouns; No nominal groups
Passive voice	Prevalence of verbs in a passive voice; Verbs in passive voice ≈verbs in active voice; Prevalence of verbs in an active voice
Syntactic complexity	Clause complex and hypotaxis; Clause parataxis; Simple sentence without clause

(Halliday & Martin, 1993; Koulaidis et al., 2002)

The framing notion could be elaborated into two dimensions: the hierarchical relationships and the control over the conditions for the learners' involvement in the science learning process established by classroom discourse. '*Framing refers to the principle regulating the communicative practices of the social relations within the reproduction of discursive resources, that is, between transmitters and acquirers*' (Bernstein, 2003a, p. 31). People use language to interact with others, build and maintain relationships, and use language to influence others' behaviour; use language to express the world's view and even change the world. This function is called the interpersonal function. As a communication tool, language must involve dialogue among language users. The essence of the dialogue is the communicative role of the language user: either giving or demanding, and the exchanging objects-services or information are presented as proposals or orders. The combination of the factors constitutes the four main discourse functions, *offer*, *statement*, *command* and *question* (Halliday & Matthiessen, 2004). The sentence types would be *imperative* (you or you and me), *interrogative* (WH- or yes/no), and *declarative* (Halliday & Matthiessen, 2004). Imperative clauses present the highest authority of the discourse, which indicates that the framing is strong. Although the discourse exerts control over the communicative process, the interrogative clauses are moderated. The questions give the learners options to some extent. The framing of the declarative clause is weak due to the authority of the discourse is not apparent.

The degree of the learners' involvement established by a text or a discourse is linguistically realised by the use of personal pronouns:

1. The first person singular (I) often occurs in everyday conversations, which represents the speaker with weak audiences' involvement;
2. The second person singular (You) represents the audience. It clearly expresses that the audience is included in the communication process, which indicates a strong framing.
3. The first person plural (We) and the second plural person (You) refer to a group of people, not specifically. Therefore, the framing is moderated.
4. The third singular, plural or nominal group indicates a withdrawal of both speaker and audience from the communication process. Therefore, the framing is weak.

(Halliday & Matthiessen, 2004; Koulaidis et al., 2002)

Table 2.3 The framing markers and value

Framing markers	Framing value (from high to low)
Sentence type	Imperative; Interrogative; Declarative
Person pronouns	The second person singular (You); The first person plural (We), and the second plural person (You) ; The first person singular (I); The third singular, plural person or nominal group

The intervention of multidisciplinary theory has enriched the interpretation perspective of classroom discourse research. However, these perspectives seem to avoid the professional problems of classroom teaching and learning and regard classroom talk as empirical evidence materials. Hymes and Farr (1982, p. 14) stated that ‘[p]*rogress in linguistics is not always pay-off in pedagogy*’, ‘[i]*f education, then, is going to have the insight into classroom discourse that it needs and deserves, it can not wait upon the progress of linguistics and the social sciences*’. The study of science classroom teaching should include an emphasis on scientific reasoning and internal logic's disciplinary characteristics. Analysis methods and frameworks still need further exploration of empirical research related to science classroom discourse.

2.3 Studying discourse in the science classroom

School science introduces scientific concepts, conventions, laws, theories, principles and ways of working in science to students (Mortimer & Scott, 2003). Science teaching supports science learners in accomplishing knowledge transformation from ‘life’ knowledge to ‘scientific’ knowledge (Leach, Driver, Millar, & Scott, 1997). The distinction between everyday, school and real science is required (Deng, 2001). Science teachers must talk about science to make meaning possible for students, assisting them in understanding concepts. People gain experiences from life, work and study. These constitute ‘everyday’ science, lacking organisation, possibly unscientific enough and error-prone. ‘Real’ science within the scientific community needs to be described using academic, rigorous and ‘scientific’ language. To understand such a language system, one needs sufficient background knowledge. At the secondary-school level, school students are unlikely to learn science as ‘real’ scientists. This means school science needs to mediate everyday knowledge and real science.

Educational researchers regard classroom discourse as the medium to study the impact of classroom discourse on students’ learning (Howe & Abedin, 2013; Zhong, 2013). Research on classroom discourse focuses on traditional classroom talk and interactions (Cazden & Beck, 2003). Classroom education needs in-depth exchanges not limited to teachers' simple questions searching for students' short and correct answers. This section reviews relevant studies investigating the impact of discourse in science classrooms. Three themes are presented, namely ‘discourse as an instructional scaffold in class’ (section 2.3.1), which reviews the role of discourse in the classroom; ‘classroom discourse models’ (section 2.3.2) which summarizes research models on classroom discourse; and ‘professional development’ (section 2.3.3) which presents implications on the way of improving teachers' ability to use classroom discourse. In addition, considering the research sample is Chinese physics classroom teaching, the studies of classroom discourse in Chinese science classroom are included and reviewed in section 2.3.4.

2.3.1 *Discourse as an instructional scaffold in class*

As the scaffolding of teaching, discourse should play a linking role. Teachers should consider both knowledge of students and scientific content when preparing discourse. Firstly, making school science "life-like" is essential. Although classroom teaching aims to teach students to talk and think in line with scientific community discourse, students are beginners in science. Scientific terms are unfamiliar to students. Instructional discourse plays an essential role in improving students' level of understanding of scientific terms. Classroom language should be close to learners' language. Development and learning need a scaffold from social contexts to individual understanding (Vygotsky, 1978). A challenge for teachers is to endow life experiences with student-understandable scientific explanations. Using life-like teaching strategies in science lessons creates a relaxed atmosphere, inspiring and cultivating interest and motivation (Zhu & Zhang, 2010). A progressive educational approach offers opportunities for pupils to share knowledge, guiding them using scientific language step by step (Edwards & Mercer, 2013). Secondly, supporting students to conceptualise life experiences is vital for classroom teaching (Mercer, 2008). Students use their natural understanding to describe their world. In science lessons, affairs in daily life are connected to scientific terms, for example, gravity, sound propagation and air pressure. These are different from everyday conceptual knowledge. Students learn to talk and think within the scientific community discourse, with their everyday experiences as a starting point. The scientific learning is the process of conceptualizing everyday knowledge. Inheriting students' life-like discourse and linking scientific discourse are both the target of teaching discourse.

Knowledge-building is a process of removing the false and retaining the true. Some prior experiences are information-misconceptions that conflict with scientific understandings. Teachers must find misconceptions and guide students in establishing reasonable understandings of phenomena (Wandersee, 1986). Guiding students into scientific discourse requires insight into students' personal discourse about everyday scientific knowledge. Classroom teaching should not over-emphasise scientific community discourse while overlooking students' current levels of knowledge.

On the issue of concept development, Vygotsky (1986) focused on scientific concepts and everyday concepts. The former refers to concepts mastered in the teaching process, while the latter refers to concepts formed in daily life. The comprehensibility and randomness of scientific concepts distinguish them from everyday concepts essentially: everyday concepts are vague and restricted in application, and arise from children's personal experiences. The development of the former has considerable influence on the formation of the latter. The development of scientific concepts is also necessary to develop everyday concepts to a certain extent (Vygotsky, 1986). In particular, the development of scientific concepts and everyday concepts proceeds in opposite directions: everyday concepts develop ‘bottom-up’ from low-level attributes to high-level attributes of concepts, and the scientific concept is developed ‘top-down’ (Vygotsky, 1986). However, the opposite development path does not eliminate the interconnectedness and interaction of the two conceptual forms (Vygotsky, 1986).

Bernstein (1999)’s distinction between horizontal (everyday) and vertical (scientific) discourse coincides with Vygotsky's two conceptual forms. Horizontal discourse expresses common knowledge. Its features are ‘oral, local, context-dependent and specific, tacit, multi-layered, and contradictory across but not within contexts' (Bernstein, 1999, p. 159). Vertical discourse shows specialised knowledge. It has clear and coherent structure, like natural science, and owns specialised language and criteria for text production and transfer, as social science. According to different knowledge acquisition mechanisms, Bernstein (1999) advocated that vertical discourse can be further divided into Horizontal and Hierarchical knowledge structures. One is knowledge represented by humanistic and social science. This knowledge is relatively independent, with unsystematic methods and non-uniform standards, and has horizontal structure characteristics (shown as Figure 2.1). The other is science knowledge or natural science

Figure 2.1 A diagram of Horizontal and Hierarchical knowledge structures

knowledge. This knowledge is highly systematic and developed by scientists. Its purpose is to cover the largest number of empirical rules or principles with universal propositions or theories. Development of hierarchical knowledge relies on established knowledge, which has the characteristics of hierarchical structure (shown as Figure 2.1). Bernstein (1999) focused on generating new knowledge, including the integration and induction, accumulation and segmentation of knowledge. However, his model does not explain how to accumulate knowledge in the curriculum or the student's learning process.

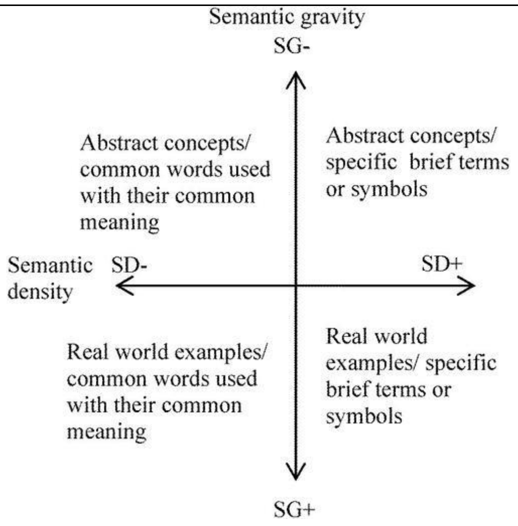
Vygotsky and Bernstein distinguished existing concepts or discourse into two forms. This distinction is not intended to classify, but refers to relationship between content, which is used to distinguish the nature of content. This distinction restricts discourse to a segment with two endpoints (everyday-scientific concepts or horizontal-vertical discourse), ‘all the various theories on thought and language stay within the confining circle’ (Vygotsky, 1986, p. 2). However, the context of classroom discourse is complex and intricate. Classroom discourse swings between the two endpoints.

Maton (2013) developed a four quadrants model, known as the ‘semantic plane’ and proposed the concepts of cumulative knowledge building and semantic wave. The semantic principle of Legitimation Code Theory (Maton, 2007, 2011, 2013, 2014b) regards the field of social practice as various semantic structures, and the organisational principles of such semantic structures are conceptualised as semantic code, which is represented by semantic gravity (SG) and semantic density (SD). '*Semantic gravity (SG) refers to the degree to which meaning relates to its context*' (Maton, 2013, p. 11). Maton uses stronger (+) or weaker (-) to represent continuous change in SG. The stronger the SG, the more semantic tends to the context or the more dependent on context. Conversely, the weaker the SG, the more the semantics are separated from the context, otherwise are the less dependent on the context. The strength of the semantic gravity depends on the specific situational context. SD refers to '*the degree of condensation of meaning within socio-cultural practices, whether these comprise symbols, terms, concepts, phrases, expressions, gestures, clothing, etc*' (Maton, 2013, p. 11). Similar to SG, SD also presents continuous changes with strength. The stronger (+) the SD, the more meaning the symbol implies in practice. Conversely, the weaker the SD, the less meaning the symbol implies. The degree of semantic compression in practice relates to the semantic structure. For example, in academic research, when researchers use an abstract term for summarising a series of specific features of the term, the SD increases. When moving from a symbol or term with a more abstract and high-density meaning to a symbol or term with a more specific and low-density meaning, the SD decreases. For example, when interpreting complex technical terms, researchers use concise terms with a limited number of meanings, therefore, in this interpretation process, the number of the features contained in the meaning is reduced, and the SD is weakened. Maton describes the relationship between SG and SD in the following chart (Table 2.4).

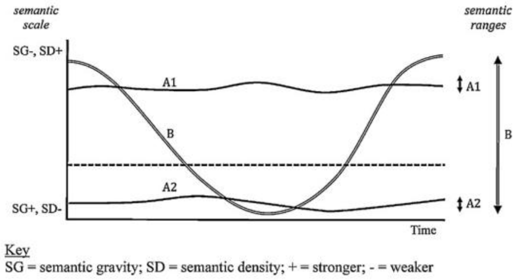
Table 2.4 A comparison of distinction of discourse

Vygotsky (1986)	Everyday discourse	⇄	Scientific discourse
Bernstein (1999)	Horizontal discourse	⇄	Vertical discourse

Maton (2013)



The semantic plane (Maton, 2014a, p. 184)



Maton (2013, p. 13)

Maton (2013) points out that the semantic wave is a prerequisite for realisation of cumulative knowledge construction. He believes that cumulative knowledge building refers to learners' transfer of the learned knowledge to the later context based on the learner's previous knowledge. When researchers study cumulative knowledge construction, teaching and learning are at the centre of education. Researchers question segmentalize, especially when knowledge is highly dependent on its context, leading to knowledge that only could make sense in specific contexts (Christie & Machen-Horarik, 2007; Maton, 2013). Therefore, Maton (2013) proposed to use the two concepts of SG and SD to describe and reveal the cumulative knowledge construction model. Learners summarise abstract concepts from more specific contexts or examples. In constructing knowledge, the degree of correlation between meaning and context becomes smaller, and the meaning the learners have is more abstract or condensed. The SG of learners is weakened, and the SD is increased. When abstract concepts are placed in a concrete context, the degree of correlation between meaning and context becomes significant, and the meaning becomes a concrete meaning. Therefore, the learner's SG increases and the SD decreases (Maton, 2013).

Martin (2013) believes that SFL provides three linguistic resources for forming semantic waves and the cumulative construction of knowledge in classroom teaching: power words, power grammar, and power composition. Power words (Martin, 2013; Maton, 2013) refers to specialized terminology with high semantic density and low semantic gravity, such as physics term like the Electric field. Power grammar encompasses the knowledge construing power of grammatical metaphor. In SFL, ideational metaphor includes experiential metaphor and logical metaphor (Halliday, 1998; Halliday & Martin, 1993; Simon-Vandenbergen et al., 2003). Experiential metaphor often achieves by nominalization to transform a verb or adjective into a participant. Logical metaphor aims to reflect the logical relationship between two clauses within a single clause. Verbalization is commonly used for this purpose, transforming connectives that typically express time and causality into dynamic processes. Power composition instructs the reader on what to write, presents the information accordingly, and ultimately recapitulates these information. Martin (2013) pointed out that power words and power grammar effectively increase semantic density. Power composition then integrates power words and power grammar into the text to form an information rhythm with regular changes in semantic density, thereby contributing to the formation of semantic waves. According to Maton (2014b), semantic wave recognition requires a specific analysis based on specific context and mood.

Martin (2013) stays within the confining circle, proposing an explanation of the role of teaching in the process of knowledge accumulation (unpacking and then packing).

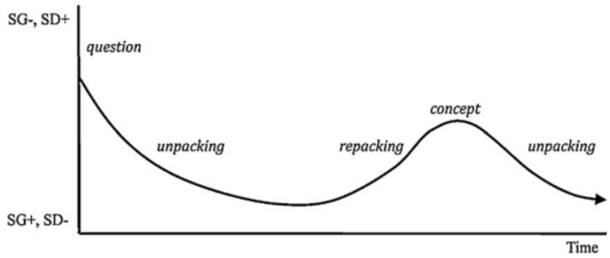


Figure 2.2 Example of a semantic wave in History teaching Maton (2013, p. 16)

Interpretation and induction form a semantic wave unit, and classroom discourse is composed of semantic waves (Figure 2.2). Larsson (2018) focuses on whole-class interactions in biology classes in Swedish lower secondary school. Maton (2013) analyses video-recordings of 100 Science (Year 8) or Biology (Year 11) and Ancient History or Modern History lessons in both urban and rural secondary schools in New South Wales, Australia. Larsson (2018) and Maton (2013) observe wavelike discourse patterns in teacher-student interactions. They describe science teaching discourse through the variables of contextuality (SG) and condensation of meaning (SD) to show a wavelike pattern or recurrent movement between and within teaching discourses (Larsson, 2018; Maton, 2013). However, this is not about science teaching per se.

This study argues that classroom discourse should be more enriched, not just for linking student discourse and scientific knowledge through discourse units. This study draws on Maton's semantic plane theory, constructing a semantic plane in a physics classroom (section 2.3.5). Givry and Roth (2006, p. 20) reconceptualised '*the notion of conception as consisting of a dialectical unit of all relevant semiotic (meaning-making) resources publicly made available by a speaker (talk, gesture, context)*'. Moreover, the richness and variety of classroom discourse are reflected in the diversity of discourse output channels, and in the multi-level functions of discourse. This requires further in-depth exploration of how existing research investigates the semantic context of classroom discourse.

The next section reviews how classroom discourse models are constructed in existing research.

2.3.2 *Classroom discourse Model*

Based on linguistic, sociological and psychological theories, educators explore classroom language to explain meaning-making. According to researchers' specific focuses, there are corresponding differences in the design and utilization of analysis frameworks. Studies analyse classroom discourse from the aspects of teaching, learning and the presentation of scientific knowledge in classroom teaching (Table 2.5).

Table 2.5 Some researchers' different classroom discourse models

Researchers	Instruction	Learning	Scientific Explanation	Organisation	Teaching and Learning Context
Flanders (1963)	O	-	-	-	-
Ogborn and colleagues (1996)	O	-	O	-	-
Reiss (2000)	O	O	-	-	O
Mortimer and Scott (2003)	O	-	O	-	-
Alexander (2008)	O	-	O	O	-
Pianta, Hamre, and Mintz (2012)	O	O	-	O	-
Vieira and Kelly (2014)	O	-	-	-	-
Magaji, Ade-Ojo, and Betteney (2018)	-	O	-	-	-

'O' indicates a component claimed to comprise in analysis framework; '-' shows components not discussed explicitly

The main analytic framework Chinese researchers use to explore science teaching is Flanders' Interaction Analysis System (FIAS) (Song, 2016). FIAS considers teacher talk, student talk and silence appearing in teaching. The chain of language evaluates the pattern of discourse. It seems suitable for evaluating Chinese secondary school classroom interaction (Li, 2011; Liu, 2011; Yang & Yan, 2010). FIAS uses the frequency of discourse modules to distinguish and identify classroom communication patterns, however, quantitative frequency cannot reflect the whole picture of teacher-student interaction.

Reiss (2000)'s qualitative analysis encompasses various aspects of teaching and learning, however, it lacks a corresponding systematic analysis framework. Reiss (2000) reports a five-year longitudinal study of pupils' learning of science in science lessons. His research described science classroom discourse and how this changed as students progressed. He found that students' science learning was influenced in many ways, including examination, home backgrounds, peer effects, gender, the value of knowledge, or the teacher's teaching style. However, Reiss (2000) only provides description of phenomena and does not propose a theoretical framework.

Ogborn and colleagues (1996) and Alexander (2008) developed an instructional discourse analysis framework for analysing the presentation of scientific knowledge in science lessons. Ogborn and colleagues (1996) used their theoretical framework (Table 2.6) to describe explanations found in science classrooms. Their theoretical framework is built on teaching experience and psychological theories, applying conceptual change theory to describe and explain classroom talk. However, descriptions emphasise scientific explanations and logic of scientific discourse, ignoring analysis of instructional strategies, organisation and other discourses. Ogborn (1996) suggests the ways books and text material play roles in teachers' explanations.

Table 2.6 Ogborn's theoretical framework

Main components	Vital features
Scientific explanations as analogous to 'stories'	•There is a cast of protagonists, each of which has its capabilities which are what makes it what it is. •Members of this cast enact one of the many series of events of which they are capable •These events have a consequence, which follows from the nature of the protagonists and the events they happened to enact.
An account of meaning-making in explanation	•Creating differences •Constructing entities •Transforming knowledge •Putting meaning into matter
Variation and styles of explanation	

(Ogborn et al., 1996, pp. 8-9)

Alexander (2008) sets out principles and repertoire for dialogic teaching (Table 2.7). Alexander's framework of dialogic teaching utilises his and other researchers' research about classroom talk. Alexander (2020) refines and expands the framework after its adoption in schools and teacher education in the UK and several other countries. These principles and repertoire contain many aspects of classroom talk. This framework deconstructs the classroom elaborately and gives corresponding explanations and suggestions for implementing dialogue teaching. The effectiveness of this framework has been tested in practice.

Table 2.7 Alexander's framework of dialogic teaching

Item		Content
Principles		•Collective; Reciprocal; Supportive; Cumulative; Purposeful
Repertoires	Talk for everyday life	•Transactional talk; Expository talk; Interrogatory talk; Exploratory talk; Expressive talk; Evaluative talk
	Talk for teaching	•Rote; Recitation; Instruction; Discussion; Dialogue

Item		Content
	Talk for learning	•Narrate; explain; instruct; ask different kinds of question; receive, act and build upon answers; analyse and solve problems; explore and evaluate ideas; discuss; argue, reason and justify; negotiate; listen; be receptive to alternative viewpoints; think about what they hear; give others time to think.
	Organisational contexts	•Whole class teaching (teacher and class); Collective group work (teacher-led); Collaborative group work (pupil-led); One-to-one (teacher and pupil); One-to-one (pupil pairs)

(Alexander, 2008, pp. 37-40)

Based on teaching observation, Vieira and Kelly (2014), and Pianta, Hamre, and Mintz (2012) summarizes an analysis framework for classroom discourse by observing phenomena and patterns in the classroom. Vieira and Kelly (2014) presented a multi-level method for science classroom discourse analysis which maps levels of the structure of human activity, proposed by Leont'ev (1978). The structure is based on cultural psychology perspectives, which provide the possibility of detailed analysis of theory-based discourse events for the analysis of classroom discourse.

Table 2.8 The structure of the levels for analysis and the episode

Levels of analysis	Related to/representative of	Frames
Activity	Need, motive, general goal / One class	Class presentation frame
Action	Goal / Discursive orientation	Narrations Frame
Operation	Conditions and methods / Discursive Didactic Procedures (DDPs)	Propositional Frame
Episode of teaching	Set of actions with logic sequence of beginning, middle and ending phases with a common theme	

(Vieira & Kelly, 2014, p. 2078)

Pianta et al. (2012) built up an observational instrument, the Classroom Assessment Scoring System-Secondary (CLASS-S, Table 2.9). CLASS groups teacher-student interactions into three broad domains, Emotional Support, Classroom Organization, Instructional Support, and widely used in Finland (Virtanen, Pakarinen, Lerkkanen, Poikkeus, Siekkinen, & Nurmi, 2018). Muhonen, Pakarinen, Poikkeus, Lerkkanen, and Rasku-Puttonen (2018) assess teaching discourse based on CLASS-S. They found that among the 158 Grade 6 lessons they studied, educational discourse correlated with student academic performance in language arts and physics/chemistry lessons, while the teacher-initiated model dominated science (physics/ chemistry) and language arts lessons.

Table 2.9 The CLASS-S framework of teacher-student interactions

Domains	Dimensions	
Emotional support	Positive Climate; Teacher Sensitivity; Regard for Adolescent Perspectives	Student Engagement
Classroom Organisation	Behaviour Management; Productivity; Negative Climate	
Instructional Support	Instructional Learning Formats; Content Understanding; Analysis and Inquiry; Quality of Feedback; Instructional Dialogue	

(Pianta et al., 2012, p. 116)

Mortimer and Scott (2003) analysed the classroom from the perspective of students' learning and constructs a classroom discourse analysis framework. Mortimer and Scott (2003) applied a Vygotskian perspective to set up an analytical framework (Table 2.10) of science classes. They use their framework to analyse interactions between teachers and students from two teaching sequences. Through the analysis of 'rusting' sequence, they proposed a teaching spiral (Figure 2.3). Based on analysis of the classroom themed on material structure, they discussed a teaching approach that exposed students' learning barriers by encouraging students discussion and controlling the rhythm of classroom discourse. The main discourse pattern recognised in Mortimer and Scott (2003)'s research was Initiate, Respond, Evaluate or Initiation, Response, Feedback (IRE/F). Song (2016) reviews science classroom teaching literature published in Chinese and finds that the most frequently observed classroom interaction pattern is IRE/F. This finding is supported by Howe and Abedin (2013). The pattern of classroom interactions should be IRE/F in China and English-speaking countries. However, intentions focus on the learning process and do not involve other factors. For example, the scientific concept itself, curriculum requirement, and textbook also influence teachers' intention of their talk.

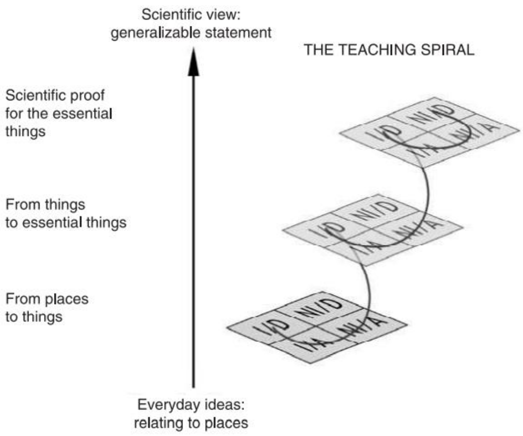
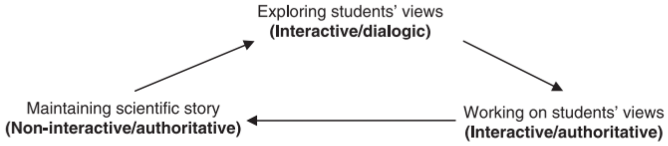


Figure 2.3 The 'teaching spiral' for the rusting sequence

Table 2.10 Mortimer and Scott's Analytical Framework

Focus	Teaching Purpose	Opening up the problem; Exploring and working on student's views; Introducing and developing the scientific story; Guiding to work internalisation; Guiding students to apply, and expand on the use of, the scientific view, and handing over responsibility for its use; Maintaining the development of the scientific story
	Content	Everyday - scientific; Description - explanation - generalization; Empirical - theoretical

<table>
<tr><td>Approach</td><td>Communication approach</td><td>

(Mortimer & Scott, 2003, p. 103)</td></tr>
<tr><td>Action</td><td>Patterns of discourse
Teacher interventions</td><td>IRE/F
Shaping ideas; Selecting ideas; Making key ideas; Sharing ideas; Checking student understanding; Reviewing</td></tr>
</table>

(Mortimer & Scott, 2003, pp. 25-45)

These models of analysis classroom discourse are all based on teacher-led classes. Magaji, Ade-Ojo, and Betteney (2018) offers an interactive discourse model focused on students-led questioning and feedback and involves a sequence of Student initiation, Student response, Student probing and Student evaluation (SI-SR-SP-SE). Studies have linked the quality of dialogue to how students learn. Teachers orchestrate teaching discourse according to students' cognitive processes (Fang, 2020; Salloum & BouJaoude, 2019). The central goal of the design of discourse and activities in class is for students to construct understanding and engage in higher cognitive processing levels (Christian & Talanquer, 2012).

Most of the existing classroom discourse analysis frameworks focus on teaching, learning, knowledge presentation, classroom organization and teaching background (shown in Table 2.5). Researchers elaborate deconstruction the corresponding aspects of classroom discourse based on their research preferences are analysed in detail according to the research preferences.

Elaborate deconstruction of classroom discourse helps teachers understand classroom discourse and design their discourse model. When teachers clearly understand the discourse model they can help students make their thinking explicit (Brown & Spang, 2008; Kawalkar & Vijapurkar, 2013). However, one lesson may not be enough for the student to understand scientific content, or establish a knowledge system (de Robles, 2018). Quality discourse models could be a model for students to imitate and offer scaffolding to internalise knowledge (Murphy, Greene, Allen, Baszczewski, Swearingen, Wei, & Butler, 2018; Rappa & Tang, 2018). Elaborate repertoires significantly improve students' performance, such as designed questioning, argumentation, feedback, classroom activities and teaching materials (Alexander, 2018; Magaji et al., 2018; Muhonen et al., 2018; Rosebery, Warren, & Tucker-Raymond, 2016).

Existing classroom discourse analysis models, for science classrooms, conduct in-depth analysis from various levels and dimensions. Researchers deconstructed and interpreted the classroom from different perspectives. As Mortimer and Scott (2003, p. 72) said, *'we are not suggesting this as something to be aimed for in all teaching sequences'*. Classrooms are ever-changing and there would be no uniform template. However, classroom teaching research and theories generally revolve around teachers, students and knowledge that appears in the classroom, corresponding to teaching, learning and the explanations of scientific knowledge respectively. Classroom management and classroom climate derived from the collision of the three subjects are also considered by the existing classroom teaching research. Existing research expanded and enriched the evidence and discussion about classroom talk.

Based on the continuous elaboration and refinement of discourse analysis tools, classroom discourse research is equipped with a 'microscope' for observing teacher-student interaction. However, classroom discourse research focuses on deconstruction rather than reconstruction, making it difficult to provide an effective way for actual classroom teaching improvement. This study intends to integrate the existing classroom fragments and reconstruct the classroom appearance, to help teachers and education researchers study classroom discourse intuitively. Therefore, the main focus sorted out from the existing analysis framework, teaching, learning, knowledge presentation, classroom organization and teaching background, become the analysis focus of this study.

2.3.3 *Professional development*

Evidence is presented that explicit awareness of teaching discourse is an important part of teacher education and professional development. For example, Piliouras, Plakitsi, Seroglou, and Papantoniou (2018) refer to a discourse-focused professional development program which designed a series of activities to support teachers to teach explicitly and reflect on elements of nature of science. Four Greek Grade 5 teacher-researchers and 100 11-year-old students (divided into four groups of twenty-five students) participated in the one-year-long program. Teacher-researchers joined in discourse analysis oriented activities, learning and discussing 'what Nature of Science (NOS) should be taught?'; examining the NOS aspects communicated during science lessons through discourse analysis; developing a model of NOS teaching, and enhancing their teaching practice with NOS discourse teaching model. Piliouras et al. (2018)'s research indicates the value of involving teacher-researchers in analysing their talk about NOS, which could explicit their discourse model. Through lesson study and training, teachers reconcile students' sense-making repertoires and extensive teaching practice through science encourages, demonstrates, and build on the diversity of students' thoughts, experiences, and perspectives on scientific phenomena (Rosebery et al., 2016). Treating discourse analysis as a training and reflection tool means making discourse strategies explicit within education and professional development (Piliouras et al., 2018; Rosebery et al., 2016).

Murphy et al. (2018) suggest discourse interventions can foster teachers' and students' discourse practice, conceptual understanding and scientific argumentation. Murphy and Firetto

(2018) build up Quality Talk Science (QTs) model with four components: an ideal instructional frame, discourse elements, teacher modelling and scaffolding, and a set of pedagogical principles. Murphy et al. (2018) collect data from three high school physics and four chemistry teachers and their students in the United States, and verify QTs' effectiveness through experimental methods. They find that teachers and students performed better on critical-analytic thinking and scientific argumentation at the post-test than the comparison group (Murphy et al., 2018).

Pedagogical knowledge is vital for teacher professional development. Choice and arrangement of questions and feedback in the classroom are essential for class plan and teacher training (Chin, 2006). Bansal (2018) advocated that teaching sequence should combine the teaching purpose and the discourse model that matches each lesson's characteristics to improve teaching effectiveness. Preparation and training in organising repertoires could enhance teachers' ability to attune with sense-making repertoires in the classroom (Rosebery et al., 2016). Language-based activities and dialogic teaching are all verified effective teaching strategies in science class (Mercer, Dawes, & Staarman, 2009; Rivard & Levesque, 2011). This indicates that to improve their teaching ability, teachers should improve their ability to control the language. Teachers enhance their professional abilities through video reflections (Groschner, Schindler, Holzberger, Alles, & Seidel, 2018). This is a vital part of the lesson study process for improving teachers' teaching ability. Larrain, Moreno, Grau, Freire, Salvat, Lopez, and Silva (2017) notice the importance of curriculum for teaching and believe that curriculum materials are supported for teaching. Thus teachers should be trained to adapt to the curricula (Enyedy & Goldberg, 2004).

These directions are consistent with content covered by a teacher's professional knowledge, so training teachers' ability to implement teaching discourse will enhance teachers' professional knowledge from a linguistics perspective. A review of professional knowledge-related research follows in section 2.4.

2.3.4 *The problems of classroom interaction in the Chinese science classroom*

Students' cultural and linguistic backgrounds affect their pre-conceptions of classroom knowledge and engagement in class discussions (Pimentel & McNeill, 2016). Confucian class teaching patterns differ from Western classes, suggesting cultural discrepancy (Foong & Daniel, 2013). Howe and Abedin (2013)'s review showed that English-speaking countries dominate research investigating how dialogue is organised. In the Confucian-influenced class, few rebuttals occur in promoting argumentation (Foong & Daniel, 2013). This is influenced by culture, because students are not aware of the limitations of their decisions (Foong & Daniel, 2013). Little research focuses on teaching language in Chinese science classes (Song, 2016). Chinese research into classroom discourse began later than Western research (Peng, J., 2013). Most existing Chinese research is descriptive and reflective which does not probe behind a phenomenon (Song, 2016). Therefore, Therefore, discourse research in Chinese classroom is significance.

Chinese researchers attach great importance to discussion of power in classroom discourse. Some researchers believe that the power of classroom discourse is the essential power of teachers (Zhang, Q., 2014; Zhang, P., 2014). However, along with the rising voice of students' discourse power, teachers' power of discourse is seriously lacking, distorted or abused (Zhang, Q., 2014). Some teachers make themselves the participants of student activities and fill the whole lesson with interaction. They fail to fulfil their obligation to guide the lesson and deprive students' right to silence in class. (Liu & Guo, 2020). Researchers think classroom discourse should be guided by teacher discourse (Liu & Guo, 2020; Zhang, Q., 2014; Zhang, P., 2014). Teachers should use discipline, wit, charm, and reuse dialogue to guide students' discourse and assist students in knowledge building (Zhang, P., 2014). Researchers found that Chinese science teachers cannot guide student thinking and learning verbally (Hu, 2015; Lu, 2011; Zhao, 2012).

This study systematically analyses existing Chinese research about science classroom discourse. The database used is China National Knowledge Infrastructure (CNKI). Search strategy is: (SU = 'classroom discourse (课堂话语)'+ 'classroom interaction (课堂互动)'+ 'classroom conversation (课堂会话)'+ 'classroom communication (课堂交流)'+ 'classroom dialogue (课堂对话)'+ 'teacher's talk (教师话语)' + 'teacher-student interaction (师生互动)'+ 'teacher-student communication (师生交流)') AND (SU= 'physics (物理)'+ 'science (科学)'+ 'chemistry (化学)'+ 'biology (生物)'- 'English (英语)'- 'Chinese (语文)'- 'history (历史)'- 'politics (政治)'- 'music (音乐)'- 'geography (地理)'). This search strategy means that literature title, abstract and keyword should include keywords: classroom discourse or classroom interaction or classroom conversation or classroom communication or classroom dialogue or teacher's talk or teacher-student interaction or teacher-student communication, while including physics or science or chemistry or biology, but not including English, Chinese, history, politics, music and geography. Initial searches received 665 studies. This search is refined with 'Secondary Education' of 'Social Science'. There were 573 within 'Secondary Education'. Of these, 88 papers were published in core journals, conference proceedings or dissertations.

Authors of the 88 papers are mainly experienced, in-service secondary school science teachers or full-time normal university students. Projects are small-scale qualitative studies that probe the current state of classroom discourse through classroom observation. In general, observation protocols are based on FIAS (introduced in section 2.3.2). Teachers' evaluation of teaching effectiveness is usually carried out by teachers' informal and general observation (Lortie, 1975). The same phenomenon exists in the research of Chinese science teachers on classroom discourse. These researches are descriptive and reflective. Although they are all small-scale studies from different regions of China, there are many similarities in their research methods and conclusions (Table 2.11).

Table 2.11 A comparative example of existing discourse research on Chinese science classroom

	Research methods	Findings	Implications and suggestions
Dong (2014) (upper-secondary school in Hebei, China)	•Survey	•Teacher-centre •Lack of interaction frequency •Unitary interaction mode •Centralized interactive subject •Superficial interaction content •Students' lack of problem consciousness	•Improving teachers' ability to interactive instructional design •Creating an interactive classroom atmosphere •Enhancing students' problem awareness
Li, Y. (2015) (upper-secondary school in Shandong, China)	•Classroom observation •Survey	•Teacher-centre •Lack of interaction frequency •Unitary interaction mode •Superficial interaction content	•Increasing classroom activities •Optimizing teachers' language strategies
Bian (2014) (upper-secondary school in Tianjin, China)	•Classroom observation •Survey •Interview	•Teacher-centre •Teachers lack questioning strategies •Centralized interactive subject •Unitary feedback	• Improving teachers questioning ability •Optimizing teachers' language strategies
Wan (2015) (upper-secondary school in Jiangsu, China)	•Classroom observation •Survey •Interview	•Centralized interactive subject •Teachers lack questioning strategies •Students' lack of problem consciousness •Negative climate	• Improving teachers questioning ability •Enhancing students' problem awareness • Creating a democratic classroom atmosphere
Mi (2015) (upper-secondary school in Gansu, China)	•Classroom observation •Survey •Interview	•Teachers lack questioning strategies •Centralized interactive subject •Unitary teacher feedback	• Improving teachers questioning ability •Optimizing teacher feedback
Wang (2010) (lower-secondary school in Zhejiang, China)	•Classroom observation •Survey •Interview	• Teachers' questions are vague and meaningless • Teachers' questions are accompanied by teacher's improper non-verbal behaviours	• Creating a democratic classroom atmosphere • Individualising instructional design • Improving teachers questioning ability
Shi (2021) (upper-secondary school open classes)	•Classroom observation	•Quality classes have more interaction •Quality classes have more problem-oriented and open questions •Quality classes tend to use multimedia	• Creating physics teaching situations and increasing the interaction with students • Guarantee the principal position of students • Making physics teaching connected with students' life

Dong (2014) applies a questionnaire to investigate students' effective interaction in chemistry classroom teaching in county-level upper-secondary schools in Hebei Province, China. He takes a county upper-secondary school as the research object and randomly selected two classes from Grade 10 to 12, a total of 368 students. He finds that teachers play a leading role in students' effective interaction, and there are problems in students' interaction, such as lack of interaction frequency, unitary interaction mode, centralized interactive subject, superficial interaction content, and students' lack of problem consciousness. Li (2015) employs classroom observation and survey methods to study teacher-student interaction in classrooms. He selects nine lessons taught by three physics teachers from Grade 10 to 12 as observation objects, and collected 103 valid student questionnaires. The teacher-student interaction problems found in his study are similar to those found in Dong (2014)'s students' interaction investigation. He suggests that the frequency and quality of interaction could improve by increasing classroom activities and optimizing teachers' language strategies.

Wang (2010) used observation, questionnaire and interviews to probe the relationship between teacher-student interaction and teaching efficiency of science lessons in lower-secondary school. She held a two-week field research activity for science lessons from Grade 8 in a county lower-secondary school in Zhejiang Province, China. She found that teachers' questions were high in quantity but low in quality. For example, some teachers' questions were vague, meaningless, and accompanied by teacher's improper non-verbal behaviours that create negative climates. She advocated improving the quality of teacher-student interaction by creating a democratic classroom atmosphere, individualising instructional design, and improving teachers’ questioning ability.

Based on FIAS, Shi (2021) conducts classroom interaction analysis in 10 open classes and compares the analysis results with the scores of open classes. Shi (2021) summarises the interaction characteristics of high score open class as follows: the ratio of teacher-student and student-student interaction is relatively high; most classroom interactions were problem-oriented, and teachers raised a high proportion of open questions; Teachers are generally good at using multimedia technology. Shi (2021) gives corresponding teaching suggestions based on his research: teachers should create a reasonable physics teaching situation and increase the interaction with students; as the 'guide' and 'facilitator', teachers should fully guarantee the principal position of students, and make physics classroom closely connected with students' life.

Jin, Wei, Duan, Guo, and Wang (2016) analyse seventeen physics lesson videos (Grade 10 and 11) taught by seventeen teachers to explore Chinese physics teachers’ inquiry-oriented classroom discourse patterns. They discover that teachers recognise that cognitive processes and disciplinary reasoning are critical for teaching. However, the participant teachers were less likely to address common intuitive ideas about science concepts and principles which indicated that it should be a point for Chinese teachers professional development training (Jin et al., 2016).

Classroom interaction exists in the classroom repertoires observed by researchers. Teacher-directed interaction is universal in Chinese science classroom teaching. The frequency and quality of interaction are inadequate, and upper-secondary school students lack interaction awareness. Researchers suggest the need to improve teaching activities and optimize teaching language strategies.

While most research methods and conclusions tend to be the same, there are also cases of contrary conclusions. Researchers draw opposite conclusions on the frequency and difficulty of the questions. Dong (2014) suggests frequency is not high enough, while Mi (2015) thought it is good enough. Mi explores the situation of physics classroom interaction in rural school, drawing an opposite conclusion to Dong. This might be because researchers apply different definition standards for questioning. Mi (2015) explores questioning in physics classroom teaching through interviews, classroom observation and student questionnaire. When calculating the frequency of questioning, Mi (2015) counts pseudo-questioning, such as ‘is it right?’, ‘does it?’ and ‘understand?’, while Dong (2014) does not. Thus, the frequency of questions goes up in Mi’s research. Therefore, the quality of classroom interaction cannot be reflected only by the frequency of interaction. Ye (2015) finds that teachers’ questions are too difficult, while Zhao (2012) thought them too simple. Ye (2015) explores the teacher's questioning in physics classroom through student questionnaire, while Zhao (2012) studies the teacher's questioning in biology classroom through interview, classroom observation and student questionnaire. Ye (2015) claims that physics classroom questioning in her research is difficult and teachers do not give corresponding guidance. According to Zhao (2012)'s research, 40.7% of questioning in biology lesson are simple questions (pseudo questions), and 52.9% only stays at the knowledge level. This difference might be partly due to different subjects and participating teachers' backgrounds. In Chinese upper-secondary school, the physics course begins in Grade 10 and biology in Grade 11. Compared with biology, physics has a longer learning time, a wider range and more complex knowledge system. The participating teacher in Ye (2015)'s study is from a key upper-secondary school in Hubei Province, while the participating teacher in Zhao (2012)'s study is from a rural school in Henan province. Therefore, the school and teaching style of the research objects impacts classroom interaction.

Research methods and conclusions of studies on Chinese science classroom discourse tend to be consistent. However, there are differences according to researcher effect or contexts of classroom teaching, such as school situation and teacher's teaching style. This study uses the

Chinese physics classroom as the context, starting from the linguistic characteristics of the teaching language, then, explaining and describing the physics class in combination with the features of teachers' professional knowledge.

2.3.5 *Summary and enlightenment*

Combining the above review on classroom discourse, it is necessary to make teacher discourse explicit to improve teachers' language ability. This explicitness requires that the characteristics and context of the discourse should be vividly displayed. For the appearance of discourse, semantic waves have advantages. The semantic waves encode the abstract speech into a waveform, which could vividly show the teacher's classroom discourse's general appearance and is easy to understand.

Semantic waves need to be analysed according to the specific context because the relationship between SG and SD is not clear. Semantic waves that Maton depicted are based on the two strengths, semantic gravity and semantic density, moving together inversely. However, '*the two strengths may change independently and not always in this manner*' (Maton, 2013, p. 13). The legitimation of semantic waves requires a specific analysis based on specific contexts, and the delineation of semantic waves requires corresponding legitimation transformation methods. The key point lies in determining the relationship, hierarchical positioning, and specific movement scale between SG and SD.

LCT points out that semantic waves composed of SG and SD should be analysed in detail according to the specific context and symbol carrier (Maton, 2014b).

However, the dynamic and continuum of the semantic waves require recognition within the language frame. This section discusses the recognition framework and recognition resources of semantic waves and provides a specific operational framework for analysing and recognising different semantic wave scales in classroom discourse.

The classroom discourse of upper-secondary school physics contains much professional vocabulary, and to facilitate students' understanding, teachers prefer to use life language to explain or give examples. This study introduces Maton's four quadrants to physics classes and proposes a new semantic wave recognition system.

The topic of the force on the current-carrying wire in a magnetic field as an example:

$$F = BIL \sin\theta$$

The physics equation of the *Ampère force* given above is an example of weak SG and high SD, the first quadrant. The simple equation contains several symbols that have specific meanings in physics and their relationship (SD+). Knowledge of Ampère force is the basic knowledge of understanding the above formula, which is not present in life (SG-). Body free diagram (Figure 2.4) would also exist in this class which is the specific symbol of physics (SD+, SG+). The figures,

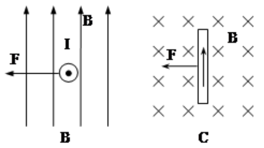


Figure 2.4 The relationship among the direction of B, I and F

for example, the free-body diagrams and circuit diagrams, are described by special symbols to explain physics problems. They require a specific physics knowledge base (SD+). Compared with physics formulas, figures are more intuitive (SG+). For example, the actual circuit diagram can still be seen. When teachers use language to describe the concept of Ampère force and the relationship between the physics quantities, semantics correspond to abstract concepts (SD-, SG-). Teachers disassemble the abstract concepts of physics (SD-), explaining them using mathematics or physics language, and the discourse is not the language of daily life (SG-). When teachers describe physics phenomena or perform classroom management, classroom discourse uses daily language to describe and give instructions. This language applies common words to describe the real world (SD-, SG+). In this research, the four quadrants are applied to four dimensions to facilitate the later data coding processing (Table 2.12).

Table 2.12 The dimensions of the semantic waves

Dimensions	Code	Description
SD+, SG-	IV	Physics equations
SD+, SG+	III	Specific real world examples or figures
SD-, SG-	II	Abstract concepts or rules
SD-, SG+	I	Real world examples or instructions

According to these four dimensions, classroom discourse is scored in a unit of semantic. Next a two-dimensional image of semantic waves of physics classroom discourse is obtained. The use of semantic wave images intuitively shows the relationship between classroom activities, words, and the explanation of knowledge. It is worth noting here that although the semantic wave looks like a smooth curve, it is delineated by category data, not continuous data. This does not mean that high-level utterances are higher than low-level ones, but divide into four dimensions. The discourse in each dimension is not identical. Subtle fluctuations in quadrants need to be described by analysing word and discourse structure (detailed in section 2.2.4).

The context of discourse lies in a science classroom, and teachers’ considerations. Existing research on classroom discourse model disintegrates classroom discourse. These classroom discourse elements provide abundant materials for this study. Moreover, combined with relevant research on teacher professional development (detailed in section 2.3.3), this research believes that classroom discourse is related to teachers professional knowledge. The next section reviews related research on teachers' professional knowledge and explores the basis for a relationship between semantic waves and teachers' professional knowledge.

2.4 The context of classroom discourse

'[L]*anguage construes, is construed by and (over time) reconstrues and is reconstrued by social context'* (Halliday & Martin, 1993, p. 24). Language is established as the realisation of social context. Malinowski believes that *'utterance and context are bound up inextricably with each other, and the context of the situation is indispensable for understanding the words'*. (Malinowski, 1923, p. 307), therefore, the relationship between word and context presents a dependent relationship. The semantic waves of LCT are cut from the context dimension, focusing on the compression and dependence of semantics in the context. The semantic wave *'does illustrate how Semantics can shed light on cumulative knowledge-building'* (Maton, 2020, p. 81). In a specific context, understanding the different types of semantic wave are still a big challenge (Maton, 2020). In this study, the specific context is the upper-secondary school physics classroom. Classroom teaching is related to teachers' professional knowledge (section 2.3.3). There is no doubt that the complexity of teaching points to the need for more extensive research into the different components that compose teachers' knowledge base and the relationships between them. This section reviews the relevant literature involved in science teachers' professional knowledge.

Teacher specialisation and professional development is the core subject of current Chinese education research (Liao, 2012). In 'Professional Standards for Middle School Teachers (Trial)' (MoE, 2012), Pedagogical Content Knowledge (PCK)[7] was regarded as an important area of teachers' professional knowledge. Possession of PCK distinguishes teacher from other subject experts (Shulman, 1986). PCK offers the possibility of investigating development of teacher's professional knowledge (Abell, 2008; Kind, 2009).

The concept of PCK was originally proposed by Shulman (1986). Shulman (1987, p. 8) later describes PCK as a 'special amalgam of content and pedagogy that is uniquely the province of teachers, their special form of professional understanding'. PCK combines content and pedagogical knowledge to define a vital component of teaching. Shulman (1987, p. 8) claims PCK

[7] PCK in the Professional Standards includes four components: Subject curriculum standards; the main methods and strategies of subject curriculum resource development and school-based curriculum development; the cognitive characteristics of students in learning specific subject content; methods and strategies for teaching and inquiry learning based on specific subject content (MoE, 2012).

has special status among these knowledge as ‘the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction’. Among these components influencing PCK, he proposed that instructional strategies and knowledge of students’ subject-matter learning difficulties are the critical elements for PCK (Shulman, 1986, 1987).

Grossman (1990) identified four components: beliefs and knowledge of the purposes for teaching a subject at different grades; knowledge about students’ understanding of subject matter; curriculum knowledge; and strategies and representations for teaching specific topics. She pointed out that ‘teacher education can provide a framework that shapes what beginning teachers subsequently learn from experience’ (Grossman, 1990, p. 111). She showed possible relationships between subject specific curriculum and teachers' practices and beliefs. While she exposited that these components are academic knowledge, she also recognized that they are personal to the individual teacher (Grossman, 1990).

Cochran, Deruiter, and King (1993, p. 266) preferred to regard PCK as pedagogical content ‘knowing’ (PCKg) built on a constructivism view instead of ‘static’ knowledge. These authors defined PCKg as ‘*a teacher’s integrated understanding of four components: pedagogy, subject matter content, student characteristics, and the environmental context of teaching*’ (Cochran et al., 1993, p. 266). They argued that PCKg is better learned and applied while classroom teaching because ‘*live teaching permits the direct interaction that shows ideas in use and opens the way to negotiating paths of understanding*’ (Cochran et al., 1993, p. 267). van Driel, Verloop, and de Vos (1998, p. 674) studied PCK from a ‘craft’ knowledge perspective to refer to ‘*the knowledge teachers have with respect to their teaching practice*’. These views revealed that PCK needs to be acquired and captured in the classroom. PCK The dynamic nature of PCK is highlighted in a critique of the *'static and inconsistent'* term '*knowledge*' in PCK. However, it is important to recognize that the static and dynamic views are two sides of the same notion. Academic knowledge, which can be taught through teacher education, is the static part of knowledge, while the dynamic part is obtained through classroom teaching practice and/or after-class reflection. The two aspects promote and penetrate each other, making them to some extent inseparable. Different researchers have different emphases and may add or remove different components based on their research (Table 2.13).

Table 2.13 Some researchers' different models of pedagogical content knowledge

Researchers	Representations and Instructional strategies	Students' subject specific learning difficulties	Purposes/ Orientations/ nature of science	Curriculum knowledge	Subject matter knowledge	Context for learning	General pedagogy/ classroom management	Assessment	Socio-cultural issues	School knowledge
Shulman (1987)	P	P	K	K	K	K	K	-	-	-
Tamir (1988)	P	P	-	P	K	-	K	P	-	-
Smith & Neale (1989)	P	P	P	-	K	-	-	-	-	-
Grossman (1990)	P	P	P	P	K	K	K	-	-	-
Marks(1990)	P	P	-	P	P	-	-	-	-	-
Cochran, et al. (1993)	-	P	-	-	P	P	P	-	-	-
Geddis, et al. (1993)	P	P	-	P	-	-	-	-	-	-
Fernández-Balboa and Stiehl (1995)	P	P	P	-	P	-	-	-	-	-
Magnusson, et al. (1999)	P	P	P	P	K	K	K	P	-	-
Veal and MaKinster (1999)	P	P	P	P	P	P	P	P	P	-
Koballa, et al. (1999)	-	P	-	P	P	P	P	-	-	-
Calson (1999)	P	P	P	P	K	K	K	-	-	-
Banks, Leach and Moon (2005)	-	-	-	-	P	-	P	-	-	P
Hasweh (2005)	P	P	P	P	P	P	P	P	-	-
Loughran et al. (2006)	P	P	P	-	P	P	P	-	-	-
Rollnick et al. (2008)	P	P		P	P	P	P	P	-	-
Park and Oliver (2008)	P	P	P	P			P	P	-	-
Gess-Newsome (2015)	P	P	P	K	K	K	K	K	-	-
Kind and Chan (2019)	P	P	P	P	-	-	P	P	-	-

'P' indicates a component claimed to comprise PCK; 'K' denotes a component belongs to teachers' knowledge base; '-' shows components not discussed explicitly

This study focuses on science classroom teaching, therefore, the components of science teachers' PCK and how it affects classroom practice will be discussed in the following part.

Magnusson et al. (1999)'s model was adopted widely (Figure 2.5). They conceptualised PCK

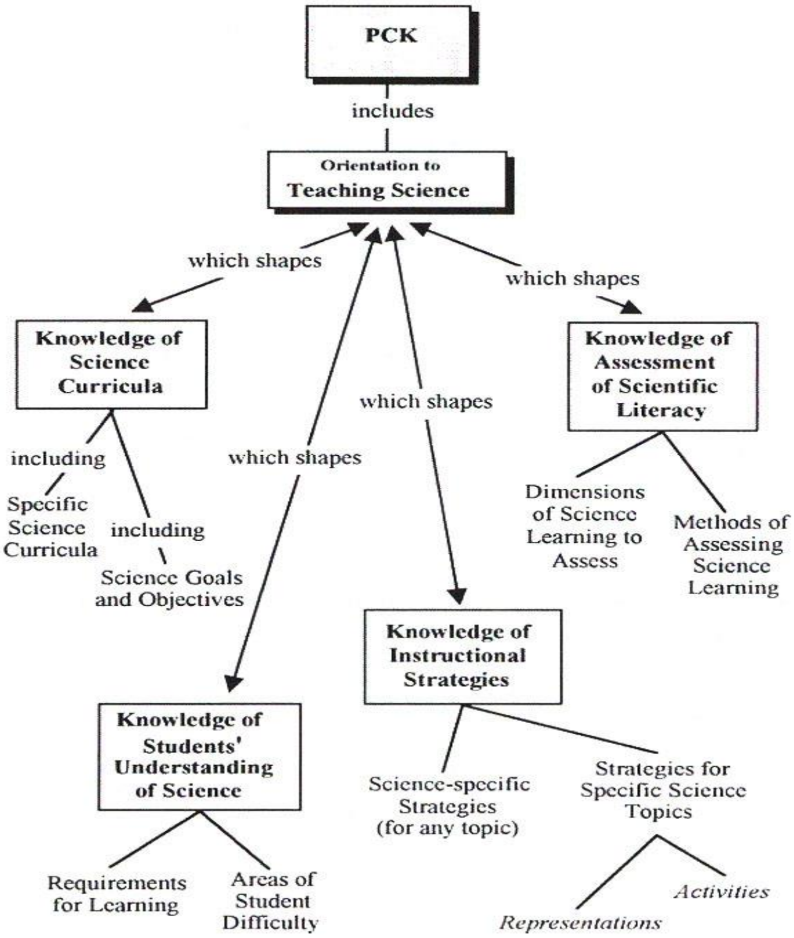


Figure 2.5 Components of PCK for science teaching (Magnusson, Krajcik, & Borko, 1999, p. 99)

for science teaching as comprised of five components: orientations to science teaching, which was added as a guide, guiding and being influenced by the other four components; knowledge and beliefs of science curriculum; knowledge and beliefs of students' understanding of specific science topics; knowledge and beliefs of assessment in science; and knowledge and beliefs of instructional strategies in science. Magnusson et al. (1999, p. 111) stated that the '*development of PCK is not a straightforward matter of having knowledge; it is also an intentional act in which teachers choose to reconstruct their understanding to fit a situation*'.

Park and Oliver (2008) proposed a pentagon model of PCK for science teaching, reorganised the five components in Magnusson et al. (1999)'s model and emphasized the interaction among them and teachers' reflection on teaching practices.

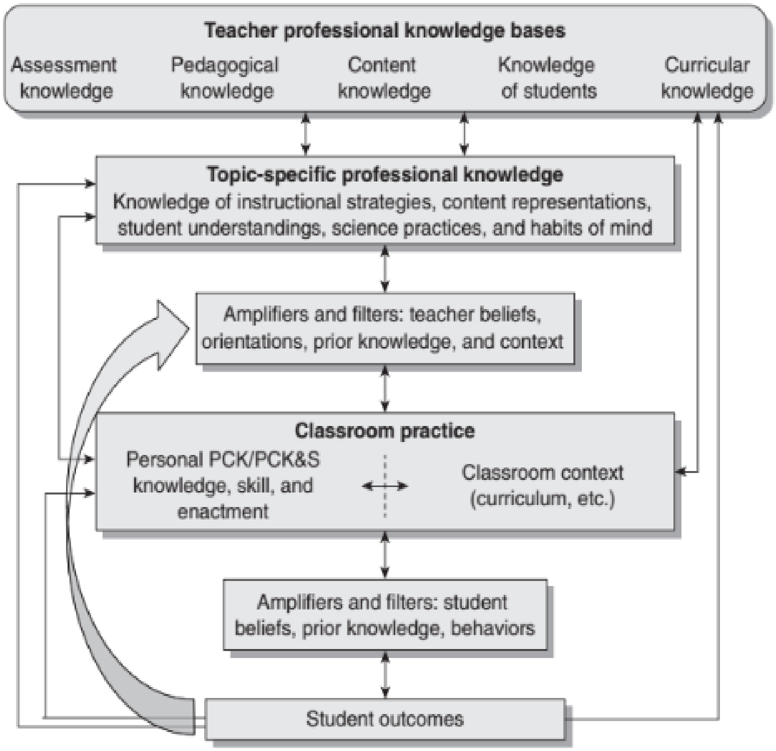


Figure 2.6 Model of teacher professional knowledge and skill including PCK (Gess-Newsome, 2015)

A PCK ‘summit’ attended by a small group of international researchers proposed a ‘Consensus Model’ (Figure 2.6) to explain how teacher professional knowledge bases, topic-specific professional knowledge (TPSK, is broadly in line with Shulman’s original PCK definition), classroom practice and student outcomes interlink (Gess-Newsome, 2015). The Consensus Model holds that PCK is not only the mixed knowledge of content and pedagogy, but also the personal knowledge and skills of a teacher. The Consensus Model combines the two separate perspectives, 'transformative' and 'integrative' (Gess-Newsome, 1999) into one. TSPK is ‘codified by experts’ and ‘is available for study and use by teachers’ (Gess-Newsome, 2015, p. 33), while personal PCK/PCK&S are developed through classroom practices. Personal PCK is defined as ‘*knowledge of, reasoning behind, and planning for teaching a particular topic in particular way for a particular purpose to particular students for enhanced outcomes*’. ‘PCK and skill (PCK&S)’ is expounded as ‘*the act of teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes*’ (Gess-Newsome, 2015, p. 36). The development of TSPK and personal PCK/PCK&S involve other components of teacher expertise, such as student beliefs, prior knowledge and behaviour, and classroom context. However, the Consensus Model does not make specific claims about the nature or operating rules of interactions between knowledge types, how these interactions affect the development of PCK, and how PCK evolve over time (Kind & Chan, 2019).

With the deepening and increasing of research on PCK, the components of PCK vary with the research emphasis of different researchers. The Consensus Model embraces many aspects of teacher knowledge based on research evidence. However, putting PCK into a complex knowledge and skill model deviates from the existence of PCK as a probe that distinguishes teachers from other subject experts.

Kind and Chan (2019) utilise aspects of the Consensus Model and build up a structure for the amalgam, including pedagogical knowledge, knowledge of students and content knowledge into PCK model (Figure 2.7). The model presents the development of each composition over time from 'novice' to 'experienced'. This wedge-shape structure of PCK not only covers the knowledge components of PCK, but also intuitively reflects the dynamic of a teacher's personal PCK.

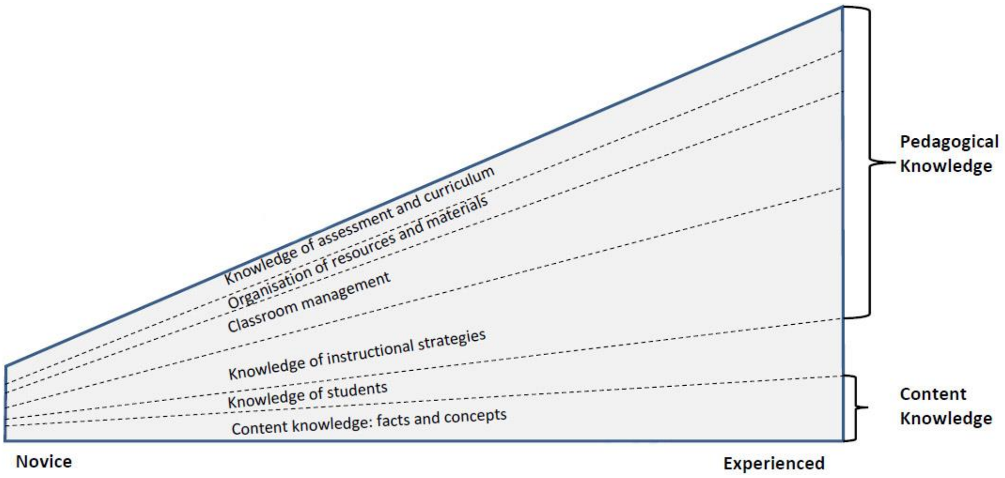


Figure 2.7 Pedagogical Content Knowledge: A Structure for the Amalgam (Kind & Chan, 2019)

This research adopts Kind and Chan (2019)'s PCK structure, taking PCK components as clues, and analyses the teaching design of electromagnetics content and teaching implementation from three aspects: content knowledge, knowledge of student and pedagogical knowledge with sub-components.

The content of electromagnetism is one of the most important and difficult fields in the upper-secondary school physics subject system (MoE, 2017b). It is the critical point and the main task for students to master the physics content of the entire upper-secondary school stage. The high degree of difficulty and abstraction of the electromagnetic content would be difficult for both students' learning and teachers' teaching (Peng, 2009). For this reason, when teaching electromagnetic content, teachers should have a wealth of subject matter knowledge and a deepening understanding of the nature of content knowledge which could ensure the smooth progress of teaching and learning.

Compared to classical mechanics, electromagnetism is a form of knowledge that is much more prevalent in everyday life, and students are often familiar with its phenomena. However, due to its highly abstract nature, students may have a vague understanding of this subject matter.

Teaching electromagnetism requires teachers to fully utilize scientific methods in physics, delve deeply into the physics-based nature of electromagnetics, and pay attention to the challenges that students may face during learning (Peng, 2009). To choose the most appropriate pedagogical strategies and to effectively organise the content of electromagnetic teaching, teachers should carefully consider these factors.

2.4.1 *Content knowledge*

Shulman (1986, p. 6) points out that content knowledge (CK) includes not only the concepts and facts of a domain, but also *'the structures of a subject include both the substantive and the syntactic structures*'. The substantive structure of a discipline addresses the fundamental question of which concepts guide disciplinary inquiry and how these concepts give rise to distinct frameworks. In this manner, the substantial structure of the discipline encompasses an additional system of concepts that delineate its content and govern its investigative approach (Schwab, 1964). The syntactic structure of a discipline, referred to as its methodology, represents the framework through which the discipline operates, encompassing its program, methods, and model for achieving objectives (Schwab, 1964). Concerning course design, the syntactic structure of a subject pertains to reconstructing the historical trajectory of inquiries into specific topics within the curriculum while maintaining equilibrium between methodological instruction and content delivery. Subject matter refers to '*bodies of knowledge, of competences, of attitudes, propensities, and values*' (Schwab, 1973, p. 510). Shulman (1987, p. 8) refined that content knowledge indicates '*the knowledge, understanding, skill, and disposition that are to be learned by school children*'. Kind (2017) states that CK includes facts about concepts and information. Gess-Newsome, Taylor, Carlson, Gardner, Wilson, and Stuhlsatz (2017) reframes Shulman's category of subject matter knowledge (SMK) and raises a new term, academic content knowledge (ACK) which is equal to Kind's. With these ideas, as a minimum, CK comprises the concepts and facts to be taught.

Table 2.14 The scientific concepts and methods involved in the selected topic of Chinese upper-secondary school physics textbook (Zhang, 2007) and curriculum standard (MoE, 2017b)

Topic	Scientific concepts and facts	Scientific methods
Magnetic phenomena and magnetic field	**Magnetic field** (Knowledge) Interactions between magnets and other magnets, between magnets and energized conductors, as well as between energized conductors themselves manifest through magnetic fields (Zhang, 2007). **Magnetic pole** (Knowledge) The magnetic strength varies across different regions of the magnet, with the region exhibiting the highest magnetic intensity referred to as the *magnetic pole* (Zhang, 2007). **Development history of magnetism in Ancient China**	Experiment Observation Idealised model method Analogy Historical-based evolutionary

	(Knowledge)	reasoning
Force on the current-carrying wire in the magnetic field	**Ampère force** (Application) The force exerted on a current-carrying wire in the presence of a magnetic field is called the *Ampère force* (Zhang, 2007). The direction of *Ampère force*: left-hand rule. The magnitude of *Ampère force*: A wire of length L, positioned perpendicular to the magnetic field B, when a current I passes through it., and the direction of the magnetic induction intensity B forms an angle θ with respect to the wire's orientation, it experiences an Ampère force $F=BIL\sin\theta$ (Zhang, 2007). **Left-hand rule** (Application) Extend the left hand, the thumb is perpendicular to the other four fingers, all lying in a plane parallel to the palm. Allow for the magnetic wire to enter through the palm and align the four fingers in accordance with the direction of current flow. Consequently, by observing the orientation of the thumb, one can determine the direction of Ampère force experienced by an energized wire within a magnetic field. This is the *left-hand rule* that determines the direction of force on a live wire in a magnetic field (Zhang, 2007).	Experiment Observation Analogy
Electric field strength	**Electric field** (Knowledge): An *electric field* is a kind of substance (MoE, 2017b). Surrounding a charge, an *electric field* is generated, exerting a force on other charges within its vicinity (Zhang, 2007). **Electric field strength** (Comprehension): Experiments demonstrate that the proportionality constant E in formula $F=Eq$ varies across different positions of the electric field, thereby reflecting the inherent characteristic of the electric field at a specific point, called *electric field strength*, $E=F/q$ (Zhang, 2007). **Electric field line** (Application): The *electric field line* is a curved trajectory indicating the direction of the electric field, with the tangent at each point representing the strength of the electric field. *Electric field lines* possess several distinctive characteristics: (1) They originate from positive charges or infinity and terminate at negative charges or infinity; (2) In an electric field, these lines never intersect due to the impossibility of having two different directions for the electric field strength at any given point; (3) Within a single diagram, denser distribution of electric field lines corresponds to regions with higher electric field strength, while sparser spacing indicates lower electric field strength. Consequently, variations in line density can be employed as a visual representation of relative magnitudes in electric field strength (Zhang, 2007).	Ratio definition method Control variable Idealised model method Analogy Experiment Observation

Chinese physics teachers' content knowledge mostly comes from Chinese physics textbook (Peng, Q., 2013; Zhang, 2007), physics curriculum standard (MoE, 2017b) and teacher's teaching book (Peng, 2009) which contain the specific subject matter knowledge and identify the taxonomy level that student should achieve. The scientific content and methods referred to three topics involved in this study are shown in Table 2.14. For example, the electric field is an essential concept in physics (MoE, 2017b). The concept of the electric field is relatively abstract because it is invisible and untouchable but objectively exists (Peng, 2009). Students would understand it gradually. In the lesson on electric field strength, the level of the concept of the electric field is knowledge[8], which means that students are only required to check the existence of the electric field through the effect of electric field on the electric charge and know it is a substance (MoE, 2017b). The level of electric field strength is comprehension. The student should understand that the electric field strength is a physical quantity that describes the nature of the electric field force. It does not depend on the existence of the test charge or the nature of the charge (Zhang, 2007). Students should know the definition of electric field strength and understand its vectorness and superposition (Peng, 2009).

The scientific methods refer to the scientific methods and reasoning suggested in the curriculum. In addition to teaching students specific content knowledge, teachers should foster students' scientific literacy (MoE, 2017b). '*Teaching people to fish is better than giving fish to people*', an old Chinese saying. Scientific knowledge may not necessarily be practised in students' lives, however, the scientific literacy cultivated by scientific methods and reasoning can benefit students. This is the critical component emphasised by the Chinese educational reform. This study introduces the reasoning model to materialise the scientific thinking raised in the new curriculum. The reasoning styles (Kind, P. & Osborne, J., 2017) contains mathematical deduction, experimental evaluation, hypothetical modelling, categorisation and classification, probabilistic reasoning and historical-based evolutionary reasoning. The hidden aim of physics teaching is fostering learners' scientific reasoning.

Physics textbooks and curriculum standard are the main source of teachers' content knowledge before teaching. However, how teachers use the textbook content to teach depends on the teachers' view of the textbook. Chinese teachers' is mainly the disseminator of the textbook, and the teaching process is mainly teaching textbook content (Guo, 2001). However, teaching content is created in the teaching process, and the process of transforming textbook content into teaching content implies teachers' personalized deduction and creation, which is the secondary development of textbooks (Yu, 2005). Based on the classroom observation and in-class notes of four upper-secondary school physics teachers on the same topic, Xu (2009) found that physics teachers would adjust teaching content in actual teaching, rather than reading from the textbook. The content analysis of teaching materials, textbook and curriculum standard, is necessary for the

[8] The concept of knowledge is borrowed from Bloom's cognitive domain taxonomy. The learning requirements for each knowledge point in Chinese upper-secondary school physics curriculum standards are based on Bloom's cognitive domain taxonomy (MoE, 2017b).

analysis of teaching content. However, it does not mean that the analysis results of the two must be consistent. This study regards teaching materials as the semantic context of teaching and the auxiliary materials of teaching.

Table 2.14 presents the explicit mention of scientific terminology and methods in Chinese upper-secondary school physics textbook and curriculum standard, which are subsequently incorporated into relevant topics for students to know, comprehend, and apply. Intuitively, comparing with the presentation of scientific terminology at knowledge level, the scientific terminology of application level presentation is more detailed (Table 2.14). I also tried to search for literature on the analysis of terminology language expression in physics textbooks among Chinese literature, however, this is precisely a research gap. The existing textbook research focuses on content difficulty, knowledge structure, exercises or experiment design, and there is hardly any research based on textbook language analysis. The forthcoming data analysis chapter (section 4.3) further scrutinize how these scientific concepts and methods are linguistically conveyed within the textbook.

2.4.2 *Knowledge of student*

Shulman (1987, p. 8) included ‘knowledge of learners and their characteristics’ as a teacher knowledge base component. In Kind’s PCK structure, knowledge of student is presented as a bridge between pedagogical knowledge and content knowledge (Kind & Chan, 2019). In classroom teaching, teachers need to express content knowledge in a way that students can understand.

Students’ approaches to learning can be classified into the deep and surface learning approach. Some students intend to understand the meaning of knowledge, while others mainly want to replicate standard answers to questions. Surface learning is a learning approach oriented towards completing external tasks and avoiding punishment, mainly based on rote memory and repeated practice and lacks in-depth thinking processing (Dolmans, Loyens, Marcq, & Gijbels, 2016). The in-depth learning approach is described as how the student intends to understand and organise the knowledge, find basic principles, weigh relevant evidence, and critically evaluate the knowledge (Biggs, Kember, & Leung, 2001). The prevailing assumption is that deep learners achieve better outcomes than those who choose the surface learning approach. However, the correlation between learning approaches and outcomes obtained are inconsistent and ambiguous (Dinsmore & Alexander, 2012). The reason identified by Dinsmore and Alexander (2012), is that the definitions of deep learning and the contexts of the relevant existing studies are vary. Scholars found that students' choice of learning approach is related to the cognitive requirements of the learning contexts and their prior knowledge on the topic under study, and is not a purely personal characteristic (Biggs & Tang, 2011; Gijbels, Richardson, & Vermunt, 2014). Therefore, in the teaching process, the teacher should consider what strategies should be applied in class to correspond to students' learning approach.

Prior knowledge and misconception are two factors that affect students learning (the prior knowledge about a specific topic is shown in Table 2.15). Prior knowledge of students refers to the understanding of various physics phenomena and processes that students have formed through their observation, experience, thinking and existing knowledge reserves (Tobias, 1994). Teaching which could activate students' prior knowledge would arise students' learning interest and promote students to integrate knowledge with their knowledge system (Tobias, 1994). However, students' prior knowledge could also be a misconception that would hinder students from learning new physics content. Misconceptions are the concepts about scientific processes hold by students when they learn a specific physics content that is counter to the beliefs and theories of scientists (Ronen, 2017).

Table 2.15 The prior knowledge about the specific topic

Topic	Prior knowledge
Electric field strength	Interaction among charges
	Basic knowledge of mechanics
	Conservation of charge
	Coulomb's law
Magnetic phenomena and magnetic field	Basic knowledge of electromagnetism
Force in the magnetic field	Basic knowledge of mechanics
	Basic knowledge of electromagnetism
	Magnetic field
	Magnetic field strength

Students may have prior knowledge and misconceptions about electromagnetics. Teachers should select teaching materials and teaching strategies in a targeted manner when preparing lessons. Although capturing students' reactions in the classroom is a capability that teachers should possess, this is still a massive challenge for teachers. Sukhomlynsky (1984, pp. 535-536) said that the teacher should pay attention to the subject and the students during teaching. The teacher should know 10 or 20 times more than what he or she wants to tell the students. Thus, the words used in the class would be smooth, and the students would not have much effort in perceiving the information. What the teacher pays attention to is not the narration but the student's thinking situation. Therefore, the teacher can see from the eyes of the students whether they understand or not. If necessary, the teacher can quickly change the lecture.

2.4.3 *Pedagogical knowledge*

Kind and Chan (2019) listed instructional strategies, classroom management, organisation of materials and resources, knowledge of assessment and curriculum as sub-components of pedagogical knowledge. They do not claim that PCK must contain all of these components (Kind & Chan, 2019). PCK components may change according to concrete circumstances.

Pedagogical strategy comprised specific teaching strategies, classroom management, classroom discourse and interaction (Gress-Newsome, 2002). Gess-Newsome and Lederman (2001) stated that ‘understanding the linguistic characteristics of the teaching-learning process can lead to creating a more effective learning environment’. The existing research identified that classroom communication is different from daily communication, which generally contains a triadic structure, IRE/F (detailed introduced in 2.3.2). Mortimer and Scott (2003) identified a teaching purpose list based on empirical research in science classrooms. Teaching strategies should be selected based on teaching purpose and context. According to the teaching context, McLeod, Fisher, and Hoover (2003) pointed out four instructional strategies, whole-class, small-group, working in pairs and working as an individual, which are also mentioned in Alexander (2008)’s framework.

Scholars define classroom management as a specific way for teachers to organise and maintain classroom environments and resources conducive to effective teaching and learning (Marzano, Marzano, & Pickering, 2003; Scarlett, 2015). It is a crucial point in teachers’ teaching reflection (Subramaniam, 2013). The quality of classroom management positively correlates with the students’ outcomes (Dorfner, Fortsch, Boone, & Neuhaus, 2019; Suviste, Kiuru, Palu, & Kikas, 2016). Aldrup, Klusmann, Ludtke, Gollner, and Trautwein (2018), based on a large longitudinal research project (5,607 secondary students, 227 classes), revealed that classroom management has a weak correlation with student outcome at student level, however, at class level, classroom management is related to school satisfaction and student achievement. Sass, Lopes, Oliveira, and Martin (2016) verified the validity of a scale built up based on the association with student engagement, instructional strategies, and classroom management, which confirmed the three factors' relationship. Existing research illustrates the importance of classroom management for teaching.

In addition to the three aspects introduced above, the analysis of topic-specific classroom teaching in this study is necessary to analyse the specific teaching behaviour in detail and explore each specific teaching case's characteristics. Because of the complexity and unpredictability of teaching behaviour, each teaching behaviour should be contextualised specifically to make sense. Therefore, this research excavates in-depth each specific teaching situation based on the three dimensions to explore the teaching strategy of electromagnetism content reflected through the language used in class.

2.5 Summary

This chapter combined the research purpose of this study with the existing literature and theories and obtained a theoretical research framework (Table 2.16), an analytical basis for subsequent classroom teaching data analysis.

'[C]*ontext and text are really two sides of the same coin - two functives [sic] of the same function of semiosis*' (Hasan, 1993, p. 86). In Bernstein's (1990b) view, the code is a naturally-obtained criterion, used to select and integrate relevant meanings and their manifestations and evoke context. Maton enriched Bernstein's theory of knowledge structure and created LCT. LCT puts forward five legitimation organisation principles: autonomy, density, specialisation, temporality and semantics (Maton, 2011, p. 65). The semantic wave of LCT is a semantic framework under its semantic principle and portrays the process of interaction and transformation between horizontal and hierarchical discourse, restricted codes and elaborated codes in a specific context. Knowledge construction is the moving process of semantic waves; that is, the process of continuous changes in the gravity and density of discourse (Maton, 2014b). The language code is realised in the language context, which is a process in which the semantic system is activated by the context of language. The context is understood through meaning, and meaning is further understood through wording (Cloran, 1999). Therefore, the text and context have an interdependent relationship. This kind of relationship is what this research wants to explore. In this study, the text is the classroom discourse, and the appearance of the classroom discourse is visualised by analysing the semantic waves of the classroom discourse (sections 2.2 and 2.3). Context is the goal that teachers and students want to achieve in the classroom, reflected in this research by analysing content knowledge, knowledge of the student and pedagogical knowledge displayed in class (section 2.4).

Table 2.16 The theoretical framework for this study

Dimensions of analysis	sub-components	
Content knowledge	Scientific concept Scientific method	
Knowledge of student	The characteristics of learning and students' status	**Language (semantic waves)**
Pedagogical knowledge	Instructional strategies Classroom management Organisation of materials and resources Knowledge of assessment and curriculum	

The theoretical framework (shown in Table 2.6) built in this chapter consists of two parts: semantic context analysis based on PCK (Kind & Chan, 2019), and semantic wave description based on Halliday and Martin (1993) 's notion of formality, Bernstein (2003a)'s framing theory and Maton’s (2013) semantic plane. This study believes that the context of classroom teaching discourse is classroom teaching, and the classroom teaching process is based on teachers' professional knowledge (section 2.4). Based on PCK (Kind & Chan, 2019), the analysis of semantic context includes three sub-contents: content knowledge, knowledge of student and pedagogical knowledge. Section 2.4.1 and section 2.4.2 sorts out teaching materials suggestions for scientific concepts, scientific method (content knowledge), and prior knowledge that students have learned before class (knowledge of student). According to Kind and Chan (2019), pedagogical knowledge consists of four aspects, instructional strategies, classroom management, organisation of materials and resources, knowledge of assessment and curriculum.

Based on Maton’s (2013) semantic plane, this study proposes a new semantic wave recognition system, which classifies classroom discourse into four-quadrants, labelling them 1-4 (section 2.3.5). According to Halliday and Martin’s (1993) notion of formality, Bernstein’s (2003a) framing theory, discriminating the small changes between the grade data can be realized (section 2.2.4) and then, the semantic waves of classroom discourse can be fitted. The recognition system of this study would transform the complex classroom discourse into waves and make it become visual.

However, language and cultural background are inherently intertwined, as extensively discussed in section 2.3.4, Chinese classrooms are deeply influenced by Confucian culture. It is crucial to ascertain whether the reconstruction of Maton's theory and Halliday Bernstein's theory, within this theoretical framework, can be effectively employed for the analysis of Chinese classroom discourse to validate its applicability in this study.

Chapter 3 Methodology

3.1 Introduction

This chapter begins by laying out the timeline (Table 3.1) of this study to discuss the methodology used to answer research questions raised in Chapter 1 and discussed via the literature review and discussion in Chapter 2. The theoretical framework described in Chapter 2 is based on theoretical consideration discussed in section 3.3. The introduction and explanation of the research methods are introduced in section 3.4. In the following sections of this chapter, sample (section 3.5), data collection (3.6), analysis (3.7) and triangulation (3.8) are discussed respectively. Section 3.9 considers ethical issues.

3.2 Timeline

The study commenced in 2017. After receiving the ethical approval (Appendix 1), based on sampling strategy, researcher contact potential participants and obtain their informed consent in October to December 2017, while data were collected from March 2018. The construction of a theoretical framework was undertaken from 2017. Between 2018 and May 2019, researcher collected the data and did a preliminary analysis. In June 2019, researcher began to conduct data analysis, and sorted out and summarized existing relevant literature. In 2020, researcher start thesis writing, which was slower than expected due to the COVID-19 outbreak. Researcher completed the first draft in 2021 and continued to revise it. In March 2023, with the support of family members and the help of my supervisor, I reorganized my thesis, and gradually revised until it was completed. The summary of the research timeline is shown in Table 3.1, including a summary of methods used to inform the research questions (RQ) identified in Chapter 1.

Table 3.1 The whole research timeline

Year	Month	Activity	Research question	Research method
2017	January to August	Theoretical research, literature review and develop a theoretical framework		
	September	Ethics application and Ethics approval granted		
	October to December	Determine sampling strategy Contact willing participants and obtain their informed consent	1,2,3	Video observation, document analysis and interview
2018	January to February	Suspension for family reason		
	March to July	1st data collection Data translation and analysis, including: Three classroom teaching videos: lesson topic – Magnetic phenomena and magnetic field; teaching plan and after-class interview	1,2,3	Video observation, document analysis and interview
	July to December	2nd data collection Translation and analysis, including: Four classroom teaching videos: lesson topic – Force in the magnetic field; teaching plan and after-class interview	1,2,3	Video observation, document analysis and interview
2019	January to May	3rd data collection Translation and analysis, including: Seven classroom teaching videos: lesson topic –Electric field; teaching plan and after-class interview	1,2,3	Video observation, document analysis and interview
	May to August	Data analysis, literature review and thesis writing		
	September to December	Suspension for family reason		
2020	January to December	Data analysis and thesis writing		
2021	January to June	Suspension for family reason		
	October to December	Thesis writing and finish the first draft		
2022	January to December	Suspension for covid pandemic		

Year	Month	Activity	Research question	Research method
2023	January to March	Suspension for covid pandemic		
	March to November	Thesis revising and writing up		

3.3 Theoretical consideration

A decision concerning methodology involves consideration of the researcher’s perspective on social reality. Bryman (2016) offers two considerations: positivism and interpretivism. *Positivism* views social issues as scientific and tries to probe social reality from this perspective. The phenomena observed are the foci of positive research (Cohen, Manion, & Morrison, 2007). Under this consideration, approaches chosen by positivistic researchers are mainly quantitative methods which entail collection of numerical data, so is a dominant technique of natural sciences (Bryman, 2016). Advantage of quantitative data include that they can be inducted, summarised and statistically examined. If data originate from a large representative sample, results may be generalised to a related population (Jacobs, Kawanaka, & Stigler, 1999).

However, quantitative approaches have disadvantages in the educational area. Quantitative methods destroy the integrity and meaning of classroom teaching and deny the participation of human in the process of classroom teaching construction (Bryman, 2016). For example, a quantitatively-oriented experimental design offers the most reliable test of causal relationships between independent and dependent variables through variable control technique (Neuman, 2014). It means, during experimental research, setting up experimental and control groups is to follow the related conditions of variable control technique. A large-scale survey can provide us with a fruitful and valid data set under a rigorous design. However, reliance on instruments and procedures and the immersion of variable analysis creates a static view of social reality which hinders the connection between research, life and the human mind (Bryman, 2016). The possibility of unrepresentative sampling and difficulties of variable control are the problematic issues, especially for educational area (Cohen et al., 2007). These cause difficulties in generalisation and may make these methods worthless.

By contrast, *interpretivism* considers that social phenomena research should be a series of common-sense constructions (Mertens, 2014) in which meanings and interpretations are significant. Extensive research in social science has been completed utilising qualitative techniques, which can help identify and characterise human interactions (Collins, 1984). However, an apparent disadvantage is that pure qualitative research is frequently too subjective and hard to replicate (Bryman, 2016). Over-reliance on the researcher's subjective views about what is significant and important and how to interpret the information leads to questions regarding the reliability and validity of qualitative data (Patton, 2015). For instance, researchers with only case study data may be unable to demonstrate their findings' external validity (Jacobs et al., 1999).

The above two perspectives stand aside one another as modes for viewing the real world. In the positivist view, observed phenomena are essential; meanwhile, an interpretivist views meanings and interpretations as paramount (Cohen et al., 2007). An emerging research approach is the paradigm of *critical theory*, which regards the previous two views as incomplete descriptions of social behaviour by ignoring social science studies' political and ideological background (Cohen et al., 2007). Critical theory aims to open up the problem-solving process to justify these new thoughts and discover potential new solutions (Myers & Klein, 2011; Young, 1991). Critical theory is expressly prescriptive and normative, requiring one to think about what behaviours should be entailed in social democracy (Fay, 1987; Morrow, 1994). Despite its critique of the above two views, critical theory does not reject any particular method but accepts all those available (Morrow, 1994), including quantitative, qualitative and mixed methods.

Specifically, within education research, critical theory has been proposed as a paradigm (Cohen et al., 2007). The critical theory has its substantive agenda (Cohen et al., 2007).

In this study, the valuable knowledge for teaching, ideological interests this serves, and how teachers reproduce knowledge in the classroom are significant questions. '[F]*rom a critical perspective, linguistic descriptions are not simply about the world but serve to construct it*' (Kincheloe, 2011, p. 291). This study focuses on reconstruction of teaching through teachers' language. Smyth (1989, p. 2) denotes a four-stage process to uncover the forces behind the teaching action: description (what am I doing?), information (what does it mean?), confrontation (how did I come to be like this?), reconstruction (how might I do things differently?). This guides for both teachers and teacher educators' critical reflection. These processes require detailed descriptions and interpretations of teaching actions. Qualitative research strategies could be suitable for uncovering mechanisms behind teaching actions.

The choice of research methods for this research, critical theory, is widely reflected in science teaching views. In China, the national curriculum standard provides educational goals and teaching content, a direct reflection of the national will in the field of education (MoE, 2017b). The unification of textbooks used by teachers and national curriculum standards makes knowledge as a static reality. People's education edition is the most widely used version, that is the textbook used by teachers participating in this study. Besides, Jiangsu education edition and Beijing Normal University edition are applied in experimental schools. Teachers do not have the right to choose the version of textbook, which is decided by Chinese Ministry of Education. However, within this scope, each teacher or teacher group's teaching methods and teaching arrangements differ, showing that understanding of curriculum knowledge vary, manifesting different knowledge values. Although the cultural and historical background influences the values, the context relates to the teaching process and teacher beliefs. Therefore, a compromise, critical theory, is appropriate to understand differences, similarities and the mechanisms behind performance.

This study is guided by critical qualitative research, as this is consistent with the aims of this study and the underlying theoretical framework. As mentioned in section 2.2.3, Fairclough (2010)'s framework includes analysing text, discourse and social practice. Therefore, a teacher's teaching plan, textbook and curriculum standard should be analysed as specific texts that relate to classroom discourse. To understand teachers' rationales for teaching, their teaching processes need to be observed and analysed. To deepen understanding of their behaviour, interviews are included to allow teachers to interpret their ideas, and their teaching plans need to be analysed. The words from the observation and teacher personal narratives create diverse interpretations and perceptions of events (Cohen et al., 2007). A complete picture of classroom teaching will be presented by combining descriptive and interpretive analysis with the theoretical framework. The methods this study adopt are explored next.

3.4 Research Methods

Based on the theoretical consideration discussed in section 3.3, the research methods, chosen by this study, are mainly qualitative methods, including video data analysis, semi-structured

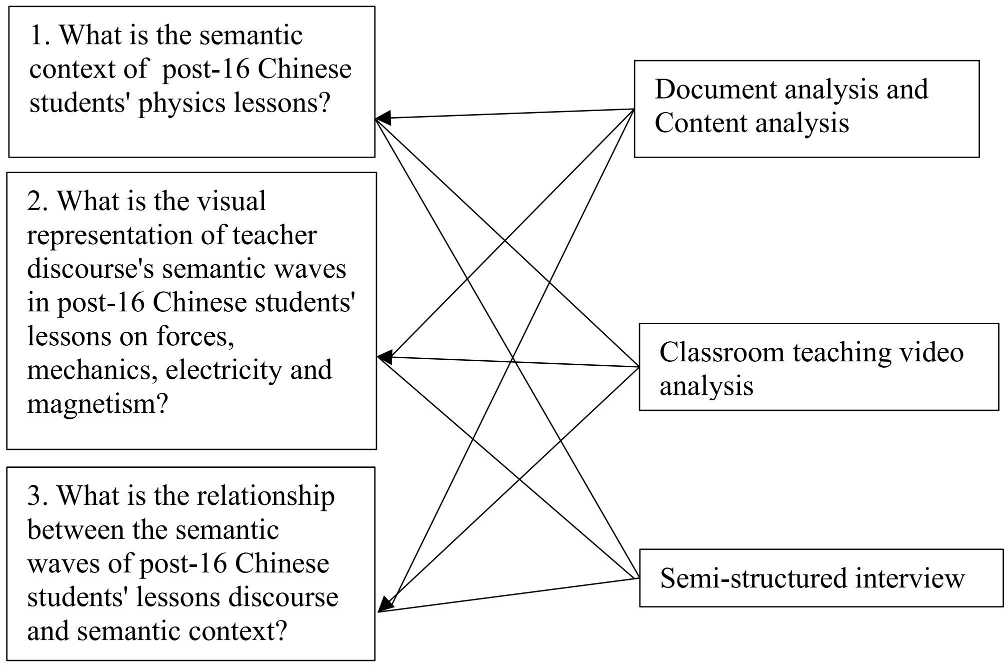


Figure 3.1 Links between research methods and research questions

interview and document analysis. Figure 3.1 (above) summarises connections between research methods and research questions.

Video data analysis help make discoveries and corroborate or disconfirm initial discoveries. Data were collected and analysed within the analytical process as a unique iterative process (Jacobs et al., 1999). This method reveals the actual situation of classroom teaching. Discoveries illustrate explicitly the language, knowledge, and strategies teachers use in class and reveal relationships between them. Finding a balance between intimacy and distance via observation methods is challenging (Bratich, 2018). Ethnography and participant observation demand involvement of investigators in activities observed by the study. The involvement makes it difficult to stay aloof (Cohen et al., 2007). Therefore, non-participant observation is a utility for probing classroom teaching and can deliberately decline to influence the class. When used in conjunction with other methods, structured observation works best (Bryman, 2016). Since this rarely provides the cause of the observed patterns of behaviour, accompanying by another method (such as semi-structured interview) to investigate the causes should be more effective. Videos capture lesson content and classroom activities, including visual (writing on a blackboard, teaching materials or the slides) and verbal content. Video data can be viewed, commented and discussed repeatedly, which allow the researcher to look into a different dimension of the recorded verbal and physical behaviour (Jacobs et al., 1999). In this controlled setting, multiple viewers collaborate to develop codes and establish reliability.

Document and content analysis delineate official materials (textbook and curriculum standards) and teaching plans with respect to the professional knowledge these contain, including ideas involved in teaching design. Document analysis may integrate quantitative and qualitative techniques (Bryman, 2016). This study considers content in documents to provide insights into the teachers' personal ideas and rationales for classroom teaching and the ethos of Chinese Ministry of Education. Bryman (2016) notes that content analysis is challenging to ascertain the answers to 'why?' questions. This study investigates 'what' factors influencing classroom teaching through the document and content analysis rather than answering 'why' questions.

Semi-structured interview interviews answer questions about why teachers design teaching in this specific way. The interviewer is the research tool, driving the quality of the information and knowledge produced during an interview via the interviewer's subject matter knowledge (Kvale, 2007). From working as a teacher before undertaking research, the researcher is able to conduct a teaching-related interview after gaining familiarity with the video and document data. The interview data reveal the teachers' underlying beliefs, design concepts, and reflections on the teaching process. A semi-structured interview is best suited for this task (Bryman, 2016). The structured interview retains a question schedule, making data processing accurate and relatively easy; however, this abandons flexibility (Bryman, 2016). Unstructured interviews tend to be similar to a conversation which would be hard to control and risks collecting irrelevant information (Bryman, 2016). A semi-structured procedure requiring participants to list typical and characteristic situations is used to identify specific episodes (Cohen et al., 2007). Therefore, this research chose semi-structured interviews to permit teachers to express their understanding and design reasons for teaching the selected topic in their way, as fully and spontaneously as possible. Before data collection, an overview of the interview (section 3.6.2, Table 3.5 The interview schedule: Categories and Questions) was provided to each participant. The content of the interview focused on how teachers use their expertise to analyse and implement the lesson.

3.5 Sampling

This study mainly used purposeful sampling, supplemented by snowball sampling and volunteer sampling to consider ethical issues and improve the feasibility of data collection. Researchers do not attempt to randomly sample study participants with a purposive sample (Bryman, 2016). The purpose of purposive sampling is to sample cases or participants strategically so that the sample or participants are relevant to the research questions. This research probes how teachers design and organise the Chinese post-16 physics classroom teaching through teaching discourse. Based on this research focus, data should be available to investigate teachers' professional knowledge that influences their teaching performance; classroom teaching records that display the classroom teaching process; and teachers' ideas about the selected topics. As discussed in section 3.4, this study chooses video materials instead of listening to teaching in the classroom to fully explore teachers' teaching discourse and avoid the influence of researcher on classroom teaching. At first, the researcher wanted to obtain videos of classroom teaching with the help of teachers. However, few teachers were willing to participate in this study due to their high work pressure and tight time.

With these purposes in mind, a snowball sampling (Cohen et al., 2007) was conducted after full consideration of ethical issues (detailed in section 3.8) and with Ethical Approval (Appendix 1.2) from the ethics committee in Durham University’s School of Education. A small group of volunteer teachers was contacted to help the researcher identify potential participant. The national project named ‘Good Lesson’ (pseudonym, the project plan is shown in Appendix 2.2), containing many ‘Good Lessons’ taught by various ‘Good Teachers’ came to the attention of this study (introduced in section 1.1.4). These Good Lessons (introduced in section 1.1.4) are used as exemplars for other teachers. Teaching preparation and teaching design are teachers' daily work, but a requirement for continuous improvement makes this challenging and stressful for teachers. Good Lessons provide teachers with novel and productive ideas and resources. Thereby, Good Lessons fits this study's aims to reveal the mechanism of classroom teaching, especially in Chinese classrooms. As the researcher is a physics teacher, this study chose physics lessons. After discussion with the volunteer teachers, the topic range was defined in the electromagnetism that belongs to the elective course[9] in post-16 physics. The electromagnetism part is one of the basic knowledge that plays a role in post-16 physics (MoE, 2017b). Electromagnetism resources in Ministry Good Lessons are the resources that teachers learn often. Electromagnetism classroom teaching reflects rich teaching resources. Therefore, it is suitable for this research.

Ministry Good Lessons in Electromagnetism, that are publicly displayed on the platform, include six lessons in topic Magnetic phenomena and magnetic (M), ten lessons in topic Force in the magnetic field (F), and eight lessons in topic Electric field (E) (shown in Table 3.2).

Table 3.2 Summary of the sampling process

Sampling process*	Achievement
Purposive sampling	Data should be available to answer: teachers' professional knowledge that influences their teaching performance; classroom teaching records that display the classroom teaching process; and teachers' ideas about the selected topics.
Snowball sampling	
Base on volunteer teachers' recommendation and the position in the physics curriculum	Database selection: The national project named 'Good Lesson' Determine the topic range: Electromagnetism
Context sampling	
Find out the ministry Good Lesson in the topic range	Six lessons in topic Magnetic phenomena and magnetic (M in short) Ten lessons in topic Force in the magnetic field (F in short); Eight lessons in topic Electric field (E in short)
Volunteer sampling	
Contact with the selected teacher to get the consent To expanding the sampling size, contact with the teachers of provincial Good Lesson	Five lessons in topic M; Five lessons in topic F; Seven lessons in topic E
Total	Seventeen lessons

* Sampling process is arranged in chronological order. A summary of the sample is shown in Table 3.3

Volunteer sampling was conducted. The researcher contacted the selected teachers and explained the research purpose, research plan and data types to be collected to them for their fully understanding of this study, and obtaining their informed consent. Only five teachers in topic M and five teachers in topic F expressed willingness to participate in this study and signed the informed consent. For expanding the sample size, researcher added provincial Good Lessons and repeated the volunteer sampling, and obtained the authorization of seven teachers in topic E.

This study collected the informed consent from seventeen teachers, corresponding to

[9] The ' elective course' in Chinese upper secondary school is a required course after the student chooses what subjects they would like to learn. Students who choose physics as one of their main subjects, the elective content in physics would be the required course.

seventeen Good Lessons, respectively five lessons in topic M, five lessons in topic F and seven lessons in topic E.

Table 3.3 Information on the selected lessons and participating teachers

Pseudonym*	Gender	Teachers' original location***	Teaching age	Educational level	Duration (Minutes)	Code of Class	Class number**	Class size	Seat arrangement
Magnetic phenomena and magnetic field (ministry Good Lessons)									
Jack[2]	Male	Anhui	10	Bachelor	41	M1	1	20	modular
Lily[2]	Female	Liaoning	8	Bachelor	41	M2	2	20	modular
Sophia[1]	Female	Xinjiang	6	Bachelor	41	M3	3	20	traditional straight-row
Leo[3]	Male	Liaoning	9	Bachelor	40	M4	4	36	traditional straight-row
Oliver[1]	Male	Sichuan	9	Bachelor	42	M5	5	66	traditional straight-row
Force on current-carrying wire in the magnetic field (ministry Good Lessons)									
Charlie[2]	Male	Jilin	10	Bachelor	41	F1	1	20	modular
Ava[1]	Female	Sichuan	5	Master	42	F2	6	20	modular
George[2]	Male	Jiangxi	10	Bachelor	41	F3	7	20	traditional straight-row
Oscar[3]	Male	Zhejiang	11	Bachelor	42	F4	3	20	modular
Freddie[2]	Male	Jiangsu	10	Bachelor	50	F5	8	56	traditional straight-row
Electric field strength (province-level Good Lessons)									
Ivy[2]	Female	Liaoning	8	Bachelor	41	E1	9	44	traditional straight-row
Mia[3]	Female	Liaoning	8	Bachelor	40	E2	10	48	traditional straight-row
Emily[3]	Female	Liaoning	7	Bachelor	41	E3	11	46	traditional straight-row
Ella[3]	Female	Liaoning	6	Bachelor	42	E4	12	45	traditional straight-row
Daisy[3]	Female	Liaoning	9	Bachelor	41	E5	13	48	traditional straight-row
Hannah[3]	Female	Liaoning	6	Bachelor	42	E6	14	46	traditional straight-row
Luna[3]	Female	Liaoning	6	Bachelor	41	E7	15	47	traditional straight-row

*The numbers shown next to teachers' pseudonyms represent the student's academic level of the teacher's school. The academic level is represented through the national ranking of the school's 2020 graduates' average score in the college entrance examination. The top 1% is marked as 1, the top 2%-4% is marked as 2, and the top 5%-7% is marked as 3.

** class number aims to give a mark of different groups of students. Teacher Jack and teacher Charlie taught the same class (1) of students with different topics. Teacher Sophia and teacher Oscar taught the same class (3) of students with different topics.

*** The distribution of Teachers' original location is shown in Figure 3.2.

Figure 3.2 The distribution of teachers' original location

*The provinces and cities marked in red are teachers' original location involved in the study

Table 3.3 introduces the basic information about the seventeen classes. Each lesson lasts for 40 to 50 minutes. Each participant teacher has a pseudonym. The teachers are from variety of places in China. The distribution of teachers' original location is marked in Figure 3.2. The students in the selected classes are in the second year[10] of their upper-secondary school, known as grade 11. The researcher received these seventeen participant teachers' informed consent. The seventeen teachers stated that they fully understand this study and agreed with their videos and teaching plans be included and to participant in a semi-structured interview.

The ten lessons in topic M and F are ministry Good Lessons. Seven of the ten teachers came to Beijing to teach pre-arranged groups of 20 students, as part of the national project. Among the samples, teacher Jack and Charlie taught topic M and F to the same class, as did teacher Sophia and Oscar. The other three ministry Good Lessons and seven province-level Good Lessons were recorded in the teachers' schools with their usual class of students for which the class size was around 50. The seating arrangement of each class is included in the information table. 'Modular' means that students sit in small groups; 'traditional' means that students sit in rows of tables with individual chairs (McCorskey & McVetta, 1978).

The academic level of the students from the school is indicated in Table 3.3, which is ranked based on the national ranking of each school's 2020 graduates' average score in the college entrance examination. The top 1% is marked as 1, the top 2-4% is marked as 2, and the top 5-7% is marked as 3. Students' academic performance is a reference point for teachers to prepare lessons. Teachers should teach students in accordance with their aptitude. It is worth noting that the school teacher Sophia comes from is the top 1% upper-secondary schools in China. However, it can rank high because it is located in Xinjiang and has national preferential policies, not entirely because of such high academic level of students. Daisy is also from a minority[11] school and has national preferential policies. The college entrance examination scores of these two school graduates are slightly higher than their real level.

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[10] Normally, students in China who have finished nine years of Compulsory education (six-year primary and three-year Junior secondary education) continue three more years of academic study in upper-secondary schools, starting at the age of fifteen.

[11] There are 56 ethnic groups in China, of which the Han is the largest. All other ethnic groups except the Han are known as minorities. Minority schools are established for the corresponding minority students, and offer courses with ethnic characteristics, such as ethnic language courses. Chinese government give minority students extra points in the college entrance examination to balance their learning disadvantages caused by differences in language and culture

3.6 Data collection

This study collects three sources of data, namely, via documents, videos, and semi-structured interviews based on the selected research methods and sampling described in section 3.4 and 3.5. The procedure of data collection is shown in Figure 3.3.

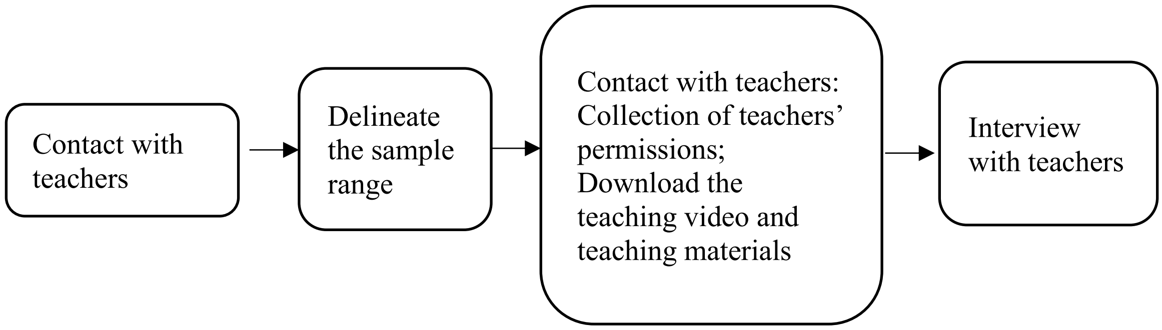

Figure 3.3 Steps in data collection

3.6.1 *Video and document*

Section 3.4 justified that this study chose non-participant observation to avoid the influence of researcher on classroom teaching. Section 3.5 discussed that few teachers were willing to spend time recording lessons to participate in this study due to their high work pressure and tight time. Meanwhile, the national project named 'Good Lesson' provides a sufficient video database, saving teachers' time and energy to participate in this study.

After full consideration of ethical issues (detailed in section 3.8) and receiving Ethical Approval (Appendix 1.2) from the ethics committee in Durham University's School of Education, teachers were contacted by researcher according to the sample range. Teachers were informed that the focus of this study were to collect the videos and teaching materials on the Good Lesson platform and would interview them about their ideas of the specific topic teaching. 17 teachers agreed to participate in this study. Among them, 7 teachers' Good Lessons were recorded by the Good Lessons Project Organizing Committee in Beijing. The remaining 10 Good Lessons were recorded by teachers in their respective schools. However, these 17 lessons all follow the video recording method stipulated by the Good Lessons Project Organizing Committee.

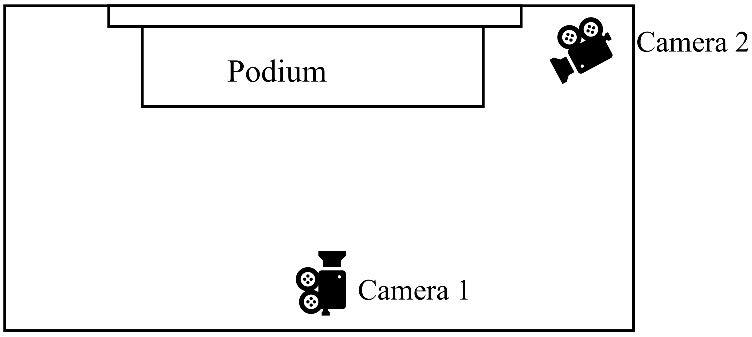

Figure 3.4 Camera position diagram

The organizing committee required that there should be two cameras (one placed in the back of the classroom, the other one placed on the right front side of the classroom, shown in Figure 3.4) setting up in each classroom. Camera 2 captured students' performances during the lesson or the demonstration experiment equipment, while camera 1 focused on the teacher, the blackboard and the slides. National project video footage was digitised and stored on https://1s1k.eduyun.cn/portal/html/1s1k/index/1.html. and is open to the public for browsing and learning from the Good Lessons.

Table 3.4 Data collection via videos and documents

Data		Quantity	Source	Relevance
Video		17	The National Project Website and Teacher Self-Stored Version*	To gain insight into the process of classroom teaching discourse in detail
Documents	Teaching plans	17	The National Project Website and Teacher Self-Stored Version*	To gain insight into the teachers' ideas and reasons for classroom teaching
	Physics Curriculum Standard	1	The website of the Chinese Ministry of Education (http://www.moe.gov.cn/)	The ethos of the Ministry of Education and the description of the curriculum content
	Textbook	3	The website of Peoples' Education Press (https://www.pep.com.cn/)	The primary teaching and learning material

* The national project website (https://1s1k.eduyun.cn/portal/html/1s1k/index/1.html) is unstable; videos and teaching materials cannot be downloaded or browsed. This research asked teachers to provide their self-stored versions of videos and teaching materials.

The data sources of the collected videos and documents, as well as their relevance to the purpose of this study, are presented in Table 3.4. Videos and teaching plan of seventeen good lessons were obtained from the National Good Lessons platform; however, due to its instability, downloading or browsing was not feasible. Consequently, this study sought assistance from corresponding teachers and acquired a teacher retention version of videos. These videos comprehensively depict classroom dynamics and are utilized in this research to describe semantic waves within classroom discourse and present pedagogical content knowledge (PCK). In addition, the physics curriculum standards and textbooks have been gathered. These curriculum standards present the recommended teaching content and its instructional depth as outlined by the Ministry of Education. Serving as a guiding document for teachers' instruction, physics curriculum standard form an integral part of teachers' pre-class PCK. This study collects curriculum standards to analyse PCK in teaching from a policy perspective, aiming to compare differences between teaching plans, and actual classroom practices in content knowledge.

The present study encompasses the primary instructional materials, namely textbooks, which hold significant value alongside curriculum standards in shaping teachers' PCK. Textbooks serve as a rich resource for educators, offering a plethora of teaching materials such as conceptual expressions, examples, experiments, and exercises. For this study, three versions of textbooks were collected: the upper-secondary school physics textbook published by People's Education Press utilized in Good Lessons; the lower-secondary school physics textbook published by People's Education Press employed to introduce relevant prior knowledge; and 'AQA Physics: A Level' used for comparative analysis of language presentation and knowledge structure across different textbooks. By comparing these three types of textbooks, valuable insights can be gained into teachers' pre-class content knowledge while identifying sources for designing their instructional discourse.

Additionally, the video material is organized based on time axis, showcasing the relationship between corresponding semantic wave and semantic context. The teaching plan comprehensively presents the key content and sequential arrangement of instruction. Analysis of the teaching plan serves as a foundation for teachers' pre-class pedagogical content knowledge (PCK) and offers insights from teachers of classroom discourse semantic patterns. Furthermore, it can also provide valuable insights for PCK development by comparing disparities between plans and actual instructional implementation.

In addition, the physics curriculum standard and textbooks have been gathered during video collection. The data utilized in this study was sourced from publicly available information on the websites of Chinese Ministry of Education and People's Education Press. Curriculum standard present the recommended teaching content and its instructional depth as outlined by the Ministry of Education. Serving as a guiding document for teachers' instruction, physics curriculum standard form an integral part of teachers' pre-class PCK. This study collects curriculum standards to analyse PCK in teaching from a policy perspective, aiming to compare differences between teaching plans, and actual classroom practices in content knowledge.

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3.6.2 *Interview*

Semi-structured interviews took place from March, 2018 after the initial analysis of the videos and teaching materials. The interview schedule (shown in Table 3.5) referred to Loughran and Mulhall (2006) 's content representation (CoRe) and the theoretical framework. The interview provides insights into the current state of physics education, highlights the practical challenges encountered during its implementation, and offers valuable recommendations for addressing these issues from teachers' perspective. The sampling method employed for this study is detailed in Section 3.5. This study employed semi-structured interviews with 17 physics teachers of Good Lessons. The interview questions encompassed various aspects such as the effective delivery of physics concepts and methods, student dynamics, selection of pedagogical strategies, maintenance of class discipline and organisation, utilization and procurement of instructional resources, comprehension of curriculum objectives, and assessment techniques.

Table 3.5 The interview schedule: Categories and Questions

Interview categories and questions
Questions about Content knowledge
What did you intend students to learn about the scientific concept and relative methods?
Why is it important for students to know this?
What else do you know about this idea?
Difficulties and/or limitations connected with teaching this idea.
Questions about Knowledge of students
Knowledge about students' thinking which influences your teaching of this topic?
What did students learn before the class?
What misconceptions do students tend to have?
Other factors about students that influence your instructional practices
Questions about Pedagogical Knowledge
Other factors that influence your instructional practices of this topic and how do you effectively manage these factors within your teaching?
e.g. Instructional strategies selection, Classroom management consideration, Organisation of materials and resources, Knowledge of assessment and curriculum
Teaching procedures (and particular reasons for using these to engage with this idea)

Questions about teaching language
Is there any special consideration in the use of teaching language? (In actual interviews, questions about the use of teaching language were followed up the previous questions.)

The interviews served two purposes. First, interviews added background information to explain why teaching procedures occurred in a specific way. Second, interviews produced depth information about teaching behaviours and how the information was expressed to students.

The interview questions were given to participant teachers beforehand. Interviewees were encouraged to describe their points of view on their teaching. The interview data is transcribed and stored in the researcher's private computer for data analysis of this. All interviews were recorded with the participants' consent and subsequently transcribed and translated into English before being validated by the interviewees. Furthermore, participants were encouraged to provide further elaboration on their statements if they believed it would enhance clarification of their viewpoints.

For analysis and annotation, coding rules were formulated (Table 3.6):

Table 3.6 Code conventions

Video code	'M' represented for the topic: Magnetic phenomena and magnetic field; '1' represents the first teacher under this topic: Jack.
Teaching plan code	'P' represented the teaching plan; for example, teacher Jack' teaching plan was coded as M1-P.
Interview code	'I' represented the interview; for example, teacher Jack' interview was coded as M1-I.

3.7 Data analysis

Researchers concerned with meaning-making in qualitative research (Willig, 2017). The fact that contrasting analyses of the same data can be generated by changing the questions asked, suggests that analysis is underpinned by assumptions the researcher makes about what is important and worth paying attention to, as well as what can be known about and through the data (Willig, 2017). This section discusses the data analysis process, including transcription(section 3.7.1), translation (section 3.7.2) and analysis (section 3.7.3). After assigning semantic values to classroom discourse according to established theoretical frameworks, researcher inputs the data into Microsoft Excel (Microsoft Office Professional Plus 2019 version) and fits a smooth curve with time as the x-axis and semantic values as the y-axis (examples are shown in section 3.7.3, Figure 3.6). NVivo is used to record the semantic contexts of classroom discourse (examples are shown in section 3.7.3, Table 3.11). Using the qualitative research software, NVivo, version 11 software enabled data manipulation, thus reducing the time that would otherwise have been spent extracting data or cross-referencing information within data.

3.7.1 *Transcription*

The transcription is a crucial data analysis (Kowal & O'connell, 2017). For better understanding and describing of the original data, transcription is necessary. The original data were transcribed, with time codes linking to the accompanying video. Transcription is a time-consuming and labour-intensive task (Bryman, 2016; Jenks, 2011). In transcribing videos and interviews what is transcribed, and what level of detail must be considered. The decision should be based on research content (Jenks, 2011). Too much content can affect readability while too little detail does not provide the researcher with an adequate analysis database (Jenks, 2011; Rymes, 2015). This study focuses on classroom discourse and analyses the mechanism behind classroom discourse. Therefore, factors influencing interactions in the classroom should be transcribed, including teachers and students' language (words and overlapping speech), silence, and non-verbal communications (writing notes on the blackboard, gesture and experimenting). For example, a teacher shows pictures in class, about the application of magnetism in daily life:

1 *(3)*

2 *[The screen shows the slide: the application of magnetic phenomena in modern life, pictures: MRI (medical), bank cards, electric fans, magnetic levitation]*

3 *The teacher points to the picture respectively]*

4 *T: Let's see the first picture on the screen, what is it?*

5 *Ss: [[MRI*

6 *T: MRI]], with such an instrument, we can image different levels of the lesion to help us analyse his or her condition.*

(M5-O)

The visual information appears on screen, teacher's and students' actions and discourse are transcribed for further analysis. Table 3.7 shows transcription conventions.

Table 3.7 Transcription conventions

T	teacher
Ss	several students speaking at once
(3)	Represent a three-second pause between utterances
(.)	Represent a micro-pause (a second or less)
bold	emphasised for discussion
[]	nonverbal information
[[ ]]	Simultaneous utterances – (beginning [[) and (end]])

During the early stages of analysing data recordings, the researcher shared the preliminary transcripts and observations with the supervisory team, participant teachers within the respective disciplines (Jenks, 2011). However, anonymity was maintained (for a discussion of ethical issues, see section 3.9). Feedbacks enabled refining of transcriptions and observations to enhance validity.

3.7.2 *Translation*

The classroom videos are Chinese teachers' classroom teaching, so the original language is Chinese. Translation work is inevitable. The main aim of translation is to achieve equivalence of meanings between two different languages. Therefore, researchers in such a meaning-making process draw on meaning and discourse to produce precise and valid interpretations. The procedure of translation and transliteration is time-consuming and resource-intensive (Regmi, Naidoo, & Pilkington, 2010). As Brislin (1970) suggested, a good practice for translation is to employ at least two competent bilingual translators who might be familiar with the research, one to translate forward and another to translate back to the original language without having seen the original text.

After initial translation, machine translation was used to translate the transcripts back to Chinese. Then, a comparison was conducted to check the correctness. Machine translation conforms to what Brislin (1970) as the back- translator does not require knowledge of the original data. Studies such as Kuo (2019) and Lin, Liu, Lee, Chang, Jaaskelainen, Yeh, and Kuo (2019) claim that compared with human translation, machine translation does not carry emotion and personal processing, but only corpus matches.

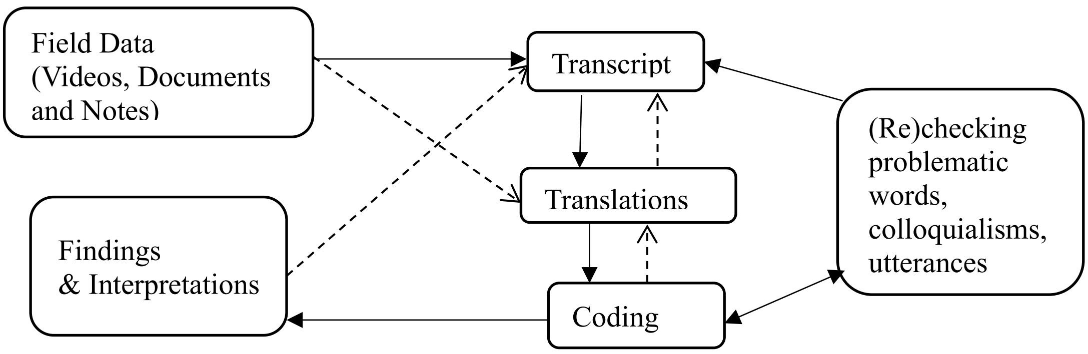


Figure 3.5 Iterative process of translation

An iterative process of translation and transliteration was used in the analysis process (illustrated in Figure 3.5). The translation process is a process of familiarising, processing, and analysing data. Every language is unique. However, differences behind this are the interoperability among human languages (Halliday & Matthiessen, 2004). The shuttle between Chinese and English has just deepened the researcher's understanding of classroom discourse.

3.7.3 *Analysis process*

This section presents the analytical procedures employed for various data types in this study. To comprehensively investigate the evolution of classroom teaching discourse over time, it is imperative to consider contextual elements as they serve as preparatory tools and aids for teachers' instruction. However, it should be acknowledged that pedagogical practices do not strictly adhere to these contextual elements. Consequently, an analysis of the classroom context encompasses formality (Halliday & Martin, 1993), framing (Bernstein, 2003a), and pedagogical content knowledge (PCK) (Kind & Chan, 2019) without describing semantic context's semantic wave.

Textbooks and **curriculum standard**s are the main teaching resources for teaching. The content and requirements in the textbook and curriculum standards are a piece of crucial background information that needs to be introduced. The analysis of language expression methods was utilized to facilitate the elucidation of classroom discourse. The analysis of knowledge frameworks and requirements, and teaching suggestions written in teaching materials, the requirements and suggestions for teachers in teaching materials answered research questions about semantic context. To have a deeper understanding of the characteristics of textbooks, the content of corresponding textbooks in Chinese lower-secondary school physics textbook and AQA upper-secondary school textbook are compared (section 1.2).

Table 3.8 The scientific concepts contained in the selected topics

Topic	Scientific concepts and facts
Magnetic phenomena and magnetic field (M)	Magnetic field Magnetic pole Development history of magnetism in Ancient China
Force on the current-carrying wire in the magnetic field (F)	Ampère force Left-hand rule
Electric field strength (E)	Electric field Electric field strength Electric field line

After a familiarity with the textbooks, breaking down the data into episodes facilitates language expression analysis. Episodes, as defined by Van Dijk (1982, p. 172) are '*coherent sequences of sentences of a discourse, linguistically marked for beginning and/or end, and further defined in terms of some kind of 'thematic unity*'. For textbook, episodes are discourse groups cantered on scientific concepts (Table 3.8).

Table 3.9 Distinction of Formality and Framing level (from section 2.2.4)

Formality			Framing	
High	moderate	Low	Strong	Weak
Three or more nominal groups; Prevalence	two or fewer nominal groups; Verbs in passive voice ≈verbs in active voice;	None nominal groups; Prevalence of verbs in an active voice;	Imperative; The second person singular (You); The first person plural (We), and the second	Declarative; The first person singular (I); The third singular, plural person or

Formality			Framing	
High	moderate	Low	Strong	Weak
of verbs in a passive voice; Terms, symbols and equations; Clause complex and hypotaxis;	Two elements of terms, symbols and equations; Clause parataxis;	Only one element of terms, symbols and equations; Simple sentence without clause	plural person (You) ;	nominal group

This study conducted an analysis and comparison of the linguistic expressions found in corresponding episodes within three textbooks, categorizing them into two considerations based on the theoretical framework, *formality* (Halliday & Martin, 1993) and *framing* (Bernstein, 2003a). As discussed in section 2.2.4, formality corresponds to the form of the language specification and analyses the complexity of the syntactic structure (Halliday & Martin, 1993) and is used to identify the way physics textbooks tends to position students within the professional knowledge system, while framing is used to identify the way textbooks locate students (Table 3.9 Distinction of Formality and Framing level).

In this study, reasoning styles (discussed in section 2.4.1) are used to identify scientific methods and reasoning. Kind and Osborne (2017) argue that the teaching content of scientific reasoning has long been plagued by a lack of clear structure. '*In the absence of such an account, the field has belittled and distorted the accomplishments of the sciences and their epistemic success to a singular algorithmic process-'the scientific method'-an account that grossly misrepresents and undervalues scientific work and its cultural contribution*' (Kind and Osborne, 2017, p9). The introduction of the scientific reasoning style addresses this deficiency and offers a more cohesive conceptual framework for the development of scientific reasoning.

Table 3.10 Code scheme for teaching plan and teacher interview

Dimensions	Main Categories	Categories
Content knowledge	Knowledge of Concept	Difficulties Relevant knowledge Definition
Knowledge of student	Knowledge of student	Student's misconceptions Student's learnt knowledge
Pedagogical knowledge	Curriculum consideration	The requirement of the curriculum The instruction of curriculum
	Teaching strategy selection	The knowledge learnt before the new class Teaching idea
	Classroom management	Classroom management
	Interaction pattern	Interaction pattern
	Organisation of materials and resources	Teaching aids Teaching slides

This research analysed the teacher's **teaching design** and **interview transcripts** based on

PCK part of established theoretical framework (code scheme shown in Table 3.10). The teaching plan is the design and planning of classroom teaching content and objectives, time arrangement and teaching materials that describes teachers' concept of a lesson. The analysis of teaching plans aims to explore a teacher's idea before class.

Table 3.11 Code scheme for video transcripts

Dimensions	Main Categories	Categories
Content knowledge	Scientific concepts	Define a theory, concept or method Elaborate the definition The rules of doing an experiment
	Scientific methods	hypothetical modelling, experimental evaluation, ideal model, parallelogram rule, vector composition, and ratio definition method
Knowledge of student	Knowledge of student	Knowledge of student
Pedagogical knowledge	Teaching strategy	Set a scene Statement of the teaching flow Guide direction of dialogue or activity Make learning or reasoning trajectory explicit Encourage student-student dialogue Analogy Give students time to think
	Interaction	Invite inquiry beyond the lesson Clarify or elaborate student's answer (Ask for) Speculate or predict Invite opinions/beliefs/ideas Invite elaboration or reasoning
	Teaching activities and materials display	Describe the equipment Describe teacher actions Activity
	Knowledge of curriculum	The teaching sequence of the subject
	In-class assessment	Check students' knowledge Praises or encourages
	Classroom management	Classroom management
	Emotion-attitude-value	History stories-describing the development of a concept Patriotism education and love of science

Video transcripts was used to analysing the classroom discourse from the pedagogical perspective and delineating semantic waves. The code scheme (Table 3.11) divides the classroom discourse into each item shown in the theoretical framework and records the relevant details. On the transcripts, teacher's utterances contained a definition of a concept labelled ‘scientific concept’ (SC). Alternatively, a description of a scientific method or the pathway to obtaining a scientific concept is labelled ‘scientific method’ (SM). Scientific methods refer to scientific reasoning theory (Kind & Osborne, 2017) and the Chinese physics curriculum (MoE, 2017), including hypothetical modelling, experimental evaluation, ideal model, parallelogram rule, vector composition, and ratio definition method. For example, if the teacher does a demonstration experiment or asks students to do a group experiment, teacher talk is coded as ‘experimental evaluation’.

Knowledge of students comprises characteristics of learning and students' academic status. Prior knowledge and misconceptions derive from analysis of student responses and interaction, teaching plans and interviews. For example, when teacher Jack was teaching Topic M, students had learnt about magnetic field in lower-secondary school, known the magnetic field, and studied the distribution of magnetic fields with iron filings. Therefore, student 2 answered Jack’s questions correctly and smoothly.

1 *T: Then how does it save the 'little pin'? On what basis?*

2 *S2: magnetic field.*

3 *T: magnetic field, right? Can you see it?*

4 *Ss: No*

5 *T: Can you touch it?*

6 *[Shaking heads]*

7 *[Hold the 'stone' up]*

8 *T: It is, actually, a natural magnetite specimen that teacher had a hard time finding it. I also want to know the magnetic field which exists around it. What can we do to study the distribution of the magnetic field around it?*

9 *Silence]*

10 *T: Can you say something about it?*

11 *[Point to S2]*

12 *S2: Use iron filings.*

13 *T: We can study with iron filings, right? Let's explore the distribution of the magnetic field around it.*

(Jack, M1-O)

Pedagogical knowledge comprises instructional strategies, classroom management and classroom discourse and interaction (Gess-Newsome, 2002). An instructional strategy is a path for teachers to impart knowledge. Teaching strategies in this research include introduction, group experiment, group discussion, demonstration experiment, lecture, and teaching aids. The introduction refers to the experiments, storytelling or teaching aids demonstration that teachers give at the beginning of the lesson to attract students' attention and enhance their interest in learning. The lecture includes question and answer, elaboration and summary. Classroom management indicates the behaviour of teachers to attract students' attention and organise classroom discipline, such as teaching activities, demonstration experiments, prop demonstration, blackboard writing, and inspections. Classroom discourse marks the discourse sequence based on the teacher's discourse and behaviour, including activities (except lectures , marked as A), initial (I), respond (A), feedback (F), evaluation (E), question (Q, change the question object to whole classroom interaction, marked as Q(whole), or to the other student, marked as Q(other)) and guide (G).

Table 3.12 Coding Scheme

Dimensions		Time	Comments
Content knowledge	Scientific concept		
	Scientific method		
Knowledge of student	Learning strategies		
	Prior knowledge and misconceptions		
Pedagogical knowledge	Instructional strategies		
	Classroom management		
	Classroom discourse and interaction		

The semantic wave theory under Maton’s LCT framework (reviewed in section 2.3.1, p. 27-28), has emerged to interpret knowledge construction in classroom discourse by analysing the strong and weak fluctuations of semantic gravity and density. The current framework of semantic wave analysis includes theme-rheme structure and given-new information, as well as the power words, power grammar, and power composition. This approach considers semantic waves as dynamic entities to enhance the explanatory power of classroom discourse. However, a challenge lies in the absence of a unified scale division standard for individual semantic waves, resulting in less specific and clear results.

Martin (2013) conducted research based on Halliday's perspective of textual function, which focuses on the unfolding of textual meaning and investigates the formation and dynamic changes of semantic waves. According to Martin (2013), semantic waves exhibit rich hierarchical variations and can be broadly categorized into three types based on their intensity: little wave, bigger wave, and tidal wave.

All three types of waveforms are formed through the utilization of theme-rheme structure as well as the interplay between given- new information. The formation units for little wave consist of small clauses, which primarily rely on information flow within these clauses. Specifically, they encompass two key aspects: theme introduction, including selection and advancement strategies for themes, as well as the introduction of new information. Middle wave formations depend on introducing hyper-themes and hyper-news at paragraph or text level. Tidal wave formations rely on expressing macro themes and macro news within the context of a text.

The relationships among these three themes are as follows: the macro theme can predict the hyper theme; the hyper theme can predict the theme; macro news helps to gather hyper news, while hyper news facilitates the accumulation of new information.

Martin (2013) proposed three linguistic resources for forming semantic waves in his research project, demonstrating a creative approach (reviewed in section 2.3.1, p. 29-30). Macnaught, Maton, and Martin (2013) emphasized that this meta-linguistic approach holds potential for enhancing teacher training and facilitating knowledge construction practices in classroom teaching. The three linguistic resources encompass power words, power grammar, and power composition. Power words refer to the specialized technical vocabulary employed in discourse, characterized by a relatively high level of semantic density; power grammar pertains to the knowledge that underlies grammatical metaphor construction; power composition instructs the reader on what to write, presents the information accordingly, and ultimately recapitulates the information. These resources enable an analysis of discourse meaning construction at multiple levels including vocabulary, grammar, and discourse organization.

The emergence of LCT has provided a novel perspective for SFL, extending the analysis of classroom discourse beyond phrasal structure, discourse power, discourse volume, and turn-taking. It views the entire classroom discourse as a dynamic process comprising multiple semantic waves that vary in size (small to large) and fluctuate over time. These waves are characterized by shifting theme structure and gradual introduction of new information, thereby connecting the entire classroom into an integrated whole. In this process, the teacher's role is to progressively break down abstract knowledge in the classroom into smaller units (description, explanation, or examples) using common sense knowledge to elucidate abstract concepts while old knowledge serves as a foundation for introducing new knowledge. The interplay between new and old knowledge results in nested layers of understanding that facilitate cumulative construction of knowledge.

However, despite the insights provided by these analytical frameworks summarized above, there are still certain issues with the frameworks: entry points for analysis lack calibration and specificity. As a result, they fail to fully capture the dynamic structure of semantic waves in a whole classroom teaching or effectively link small waves with bigger or tidal ones.

This study integrated Halliday and Martin's (1993) notion of formality, Bernstein's (2003a) framing theory, and Maton's (2013) semantic plane to construct a system for recognizing semantic waves and offering suggested scales. Additionally, it synthesized the collective semantic waves and semantic context of the entire classroom teaching over time, presenting them concurrently on a graph (Appendix 5, p. 327-343) to visually depict corresponding waveforms of semantic context and semantic waves. This visualization aids researchers and educators in analysing classroom teaching discourse.

According to Table 2.12 (p. 43) shown in Chapter 2, the classroom discourse is scored in semantic blocks. After repeatedly reading the data, this study assigns values to classroom discourse (section 2.3.5, p. 42). Within these blocks, the rise and fall of semantic waves depend on discourse formality (Halliday & Martin, 1993) and framing. For example, if a semantic block mainly presents a real-world example, then its initial assignment could be 0.5 (Table 3.13, p. 86), and the final assignment is determined by incorporating the representation of its syntactical structure (Table 3.14, p. 87). A worked example is described in the semantic wave usage guidance in 3.7.4, p. 91-93).

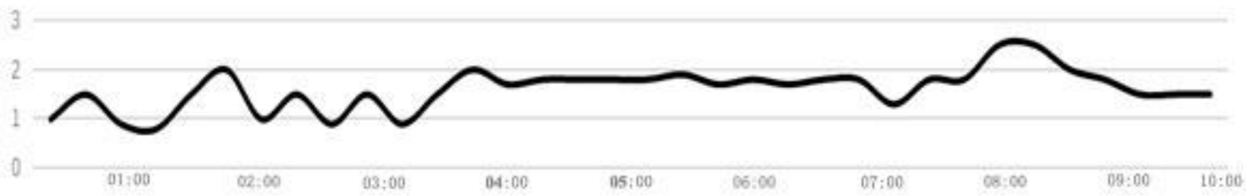


Figure 3.6 Semantic wave example diagram

A smooth curve with time as the x-axis and semantic values as the y-axis of physics classroom discourse can be obtained (an example of a semantic wave is shown in Figure 3.6) and a detailed introduction of the recognition system constructed in my study is shown in next section 3.7.4.

3.7.4 *Introduction to semantic waves and semantic context recognition*

The discourse recognition system, based on the semantic wave theory, designed for Chinese upper-secondary school physics classroom teaching, serves as a valuable tool for classroom observation and reflection. It can be effectively utilized by teachers to critically reflect upon their pedagogical practices. During the development process of this discourse recognition system, Maton's (2014a) semantic plane, formality (Halliday & Martin, 1993) and framing (Bernstein, 2003a) were consulted, while extensive research literature on exploring teaching discourse was thoroughly reviewed. The feasibility of transforming classroom discourse into semantic waves has been validated through a small-scale implementation.

The entire recognition system is divided into two components, namely semantic wave and semantic context. During the process of teaching reflection, it is necessary to analyse the two parts separately, and then combine the two parts together with the medium of time.

Semantic wave recognition resources

The classroom discourse of Chinese upper-secondary school physics contains a lot of professional vocabulary, and to facilitate students' understanding, teachers prefer to use life language to explain or provide examples. Classroom discourse is initially segmented into semantic blocks based on its semantics, with complete semantic sentences allocated to a single block. The analysis focuses on these semantic blocks. The segmentation of semantic units could be modified to align with the desired level of analytical detail. The content conveyed by the semantic blocks is further categorized into I-IV assignment regions, taking into consideration the four dimensions of semantic waves. Then, the final assignment is determined by incorporating the representation of its syntactical structure.

The four quadrants are applied to four dimensions to facilitate the later data coding process:

Table 3.13 Semantic wave value range

Dimensions	Code	Value range	Description
SD+, SG-	IV	3.5-4.5	Physics equations
SD+, SG+	III	2.5-3.5	Specific real-world examples or figures
SD-, SG-	II	1.5-2.5	Abstract concepts or rules
SD-, SG+	I	0.5-1.5	Real-world examples or instructions

The topic of the force on the current-carrying wire in a magnetic field as an example:

$$F = BIL \sin\theta$$

The physics equation of the *Ampère force* given above is an example of weak SG and high SD [value range 3.5-4.5]. The simple equation contains several symbols that have specific meanings in physics and their relationship (SD+). Knowledge of Ampère force is the basic knowledge of understanding the above formula, which is not present in life (SG-).

Body free diagram (Figure 2.4) would also exist in this class which is the specific symbol of

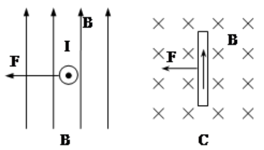


Figure 3.7 The relationship among the direction of B, I and F

physics (SD+, SG+) [value range 2.5-3.5]. The figures, for example, the free-body diagrams and circuit diagrams, are described by special symbols to explain physics problems. They require a specific physics knowledge base (SD+). Compared with physics formulas, figures are more intuitive (SG+).

When teachers use language to describe the concept of Ampère force and the relationship between the physics quantities, semantics correspond to abstract concepts (SD-, SG-) [value 1.5-2.5]. Teachers disassemble the abstract concepts of physics (SD-), explaining them using mathematics or physics language, and the discourse is not the language of daily life (SG-).

When teachers describe physics phenomena or perform classroom management, classroom discourse uses daily language to describe and give instructions. This language applies common words to describe the real world (SD-, SG+) [value 0.5-1.5].

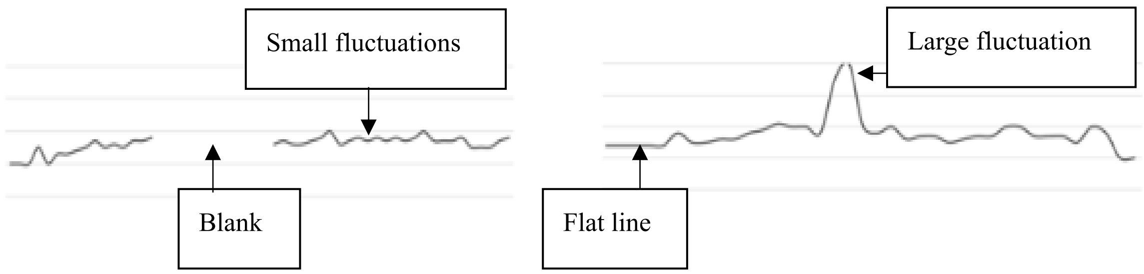
Once the discourse assignment range is established, the ultimate assignment will be determined with reference to discourse structure. The baseline of value and the allocation of additional or deducted points may be adjusted based on the current assessment by teachers or researchers, rather than being strictly revised in accordance with my predetermined value range and rule. Subtle fluctuations in quadrants need to be described by analysing word and discourse structure:

Table 3.14 Assignment rule of discourse structure

Formality markers	**Formality value (from high to low)**	**Value**
Terminology and notation	Terms, symbols and equations; Two elements Only one element	+0.3; +0.2; +0.1
Nominalisations	Existence of nominal groups of three or more nouns; Existence of nominal groups of two or fewer nouns; No nominal groups	+0.2; +0.1; +0.0
Passive voice	Prevalence of verbs in a passive voice; Verbs in passive voice ≈verbs in active voice; Prevalence of verbs in an active voice	+0.2; +0.1; +0.0
Syntactic complexity	Clause complex and hypotaxis; Clause parataxis; Simple sentence without clause	+0.2; +0.1; +0.0
Framing markers	**Framing value (from high to low)**	
Sentence type	Imperative; Interrogative; Declarative	+0.4; +0.2; +0.0
Person pronouns	The second person singular (You); The first person plural (We), and the second plural person (You) ; The first person singular (I); The third singular, plural person or nominal group	+0.2; +0.1; +0.0

Then, the final assignment is determined by incorporating the representation of its syntactical structure. Next a two-dimensional image of semantic waves of physics classroom discourse is obtained. The use of semantic wave images intuitively shows the relationship between classroom activities, words, and the explanation of knowledge. It is worth noting here that although the semantic wave looks like a smooth curve, it is delineated by category data, not continuous data. This does not mean that high-level utterances are higher than low-level ones, but divide into four dimensions. The discourse in each dimension is not identical.

Classroom semantic waves were identified four common waveforms: small fluctuations, large fluctuations, flat lines and blanks. These waveforms are commonly observed and require in-depth analysis based on the specific time point and teaching activities to gain a comprehensive understanding of pedagogy, particularly within the context of that particular instructional moment.



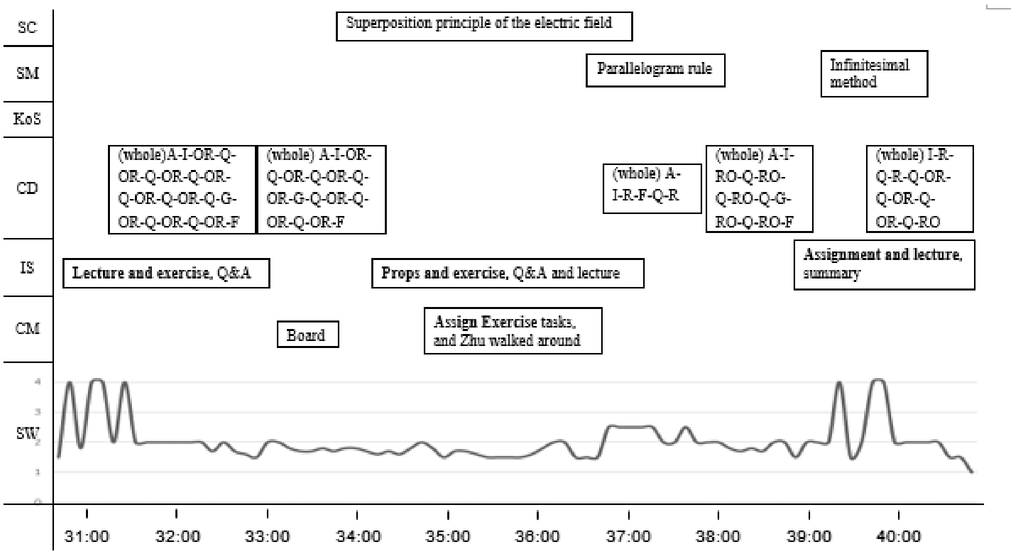
Semantic context recognition resources

Taking PCK as a clue, classroom discourse semantic blocks can be classified into content knowledge, knowledge of students and pedagogical knowledge.

Table 3.15 Semantic context recognition resources

Dimensions		Content
Content knowledge	Scientific concept	Physics concepts involved in teaching.
	Scientific method	Scientific methods refer to scientific reasoning theory (Kind & Osborne, 2017) and the Chinese physics curriculum (MoE, 2017), including hypothetical modelling, experimental evaluation, ideal model, parallelogram rule, vector composition, and ratio definition method. For example, if the teacher does a demonstration experiment or asks students to do a group experiment, teacher talk is coded as 'experimental evaluation'.
Knowledge of student	Knowledge of student	Knowledge of students comprises characteristics of learning and students' academic status derive from student responses and interaction, and related pedagogical and psychological theories. Prior knowledge, misconceptions, students' cognitive development level, students' emotional state and other factors having an impact on teaching and learning related to student.
Pedagogical knowledge	Instructional strategies	Instructional strategies include introduction, group experiment, group discussion, demonstration experiment, lecture, and teaching aids. The introduction refers to the experiments, storytelling or teaching aids demonstration that teachers give at the beginning of the lesson to attract students' attention and enhance their interest in learning. The lecture includes question and answer, elaboration and summary.
	Classroom management	Classroom management indicates the behaviour of teachers to attract students' attention and organise classroom discipline, such as teaching activities, demonstration experiments, prop demonstration, blackboard writing, and inspections.
	Classroom discourse and interaction	Classroom discourse marks the discourse sequence based on the teacher's discourse and behaviour, including activities (except lectures , marked as A), initial (I), respond (A), feedback (F), evaluation (E), question (Q, change the question object to whole classroom interaction, marked as Q(whole), or to the other student, marked as Q(other)) and guide (G).

Finally, by employing time as the medium, semantic context and semantic wave is integrated onto a graph.



Semantic waves are not limited to smooth curves, for the purpose of representing discourse continuity in Chinese background, a smooth curve is chosen in my study. Teachers or researchers have the flexibility to determine the pattern of semantic waves according to their intended portrayal of classroom discourse.

Note:

1. In the process of attributing value to discourse, it should be noted that the assigning rule serves merely as a reference point, allowing teachers to evaluate discourse based on their initial pedagogical objectives.

2. Common waveforms encompass a range of patterns, including large waveform (single peak, Crest group), small waveform, flat line, and blank, which can be considered normal, or are identified as anomalies requiring additional reflection and improvement.

3. There exists a discernible correlation between semantic wave and semantic context; however, it should not be inferred that a particular semantic context invariably aligns with a specific semantic wave.

4. Semantic context, content knowledge, knowledge of student and pedagogical knowledge,

in teacher's mind and in actual teaching, are mutually influenced and transformed. When you look at the whole class, these parts interact and fuse together, and when you focus on just one point, you can see that it is in a state at the moment, but it will change the next second.

5. Everyone has their semantic wave in mind, reflecting the content and mood of the one who describes the waveform at that moment. There is no single ‘best’ waveform, only an agreed method of assignment or recognition system. The recognition system constructed and utilized in this study functions as a catalyst, prompting Chinese educators to engage in targeted reflection on their instructional discourse, rather than being confined solely to considerations of knowledge and pedagogical approaches.

6. There is a teaching method, but there is no fixed teaching method. The value lies in obtaining the right teaching method.

Examples:

Time	Semantic Block	Semantic Context		Comments	Semantic Value*
00:00	T: Let's start our lesson. [Students standing up] Ss: Hello, teacher. T: Hello, everyone. Ok, sit down.	Classroom Management	Instructional strategies: Introduction	The traditional classroom start method which is used to calm students down	Value=0.5+0.4+0.1=1.0
00:12	We are going to learn about magnetic phenomena and magnetic fields together, so before we learn about magnetic phenomena, let's look at a video.				Value=0.5+0.4+0.1+0.1+0.1+0.1+0.1=1.4
	[A Cartoon played on the screen: there are three cartoon characters, a little pin (L), a stone (S, natural magnetite specimen), a bar magnet (B). L: I'm the little pin, today's weather is so great, let me have a walk. [fell in a hole on the ground] Oh, help, help. Who can help me! S: I am coming, I will help you. B: No, you can't, let me help you. [S and B	Classroom Management		Videos attract students' attention and interest	
00:45	fight with each other]]				Value=1
	T: They fight for 'little pin', then, who can save the 'little pin'? What do you think? (1) Please. [Point to student 1] S1: I think it's the one with NS pole can [[save the 'little pin'.				Value=0.5+0.2+0.1=0.8
	T: Why?]]				Value=0.5+0.2+0.2+0.1=1
	S1: We had learnt in junior school that it can attract metal [[objects.				
	T: Oh, it can attract]] metal objects, right? Perfect, agree with him? [Nodding]				Value=0.5+0.2+0.1+0.4=1.2
01:20					

Referred to the assignment criteria in Table 3.13 (p. 86) and Table 3.14 (p. 87), one can obtain the corresponding assignments. A detailed explanation of this process is presented in the next page, Example' Detailed Explanation.

Example: Detailed Explanation

In the initial ten seconds, the teacher and students exchange greetings in accordance with traditional Chinese teaching practices. The primary objective of greeting is to capture the attention of students and establish a quiet classroom environment conducive to subsequent instructional activities. These 10 seconds consist of everyday language (value range 0.5-1.5), thus initially valued at 0.5. The teacher's greeting carries an imperative tone (+0.4), while the subject of the sentence is the first person plural (+0.1), resulting in a final semantic module value of 1.0. The coding provided by the semantic context is integrated into classroom management and introduction, complemented by corresponding directives.

From the 12th second, the teacher introduces the lesson's content, which is currently limited to the topic title. This falls within the realm of everyday language, with an assignment range between 0.5 and 1.5. Considering that the teacher begins with traditional greetings, the baseline for the value is set at 0.5. Additionally, the teacher includes first person plural as subject (+0.1, +0.1), clause parataxis (+0.1) and terminology is present in the sentence (+0.1, +0.1). This semantic block concludes with a prompt for video demonstration delivered in an imperative sentence structure (+0.4). This semantic block serves as the initial statement in a class setting, introducing both class title and leading into video presentation while still forming part of introduction.

The approximately 30-second segment within ‘[]’ features a cartoon displayed on the screen, with dialogue consisting of everyday expressions and being assigned a value of 1. The animated content serves as material introduced into the scene, constituting part of the introduction.

According to the video content, the teacher asks questions, including interrogative sentences (+0.2) and the second plural person (You) (+0.1).

The process of a student answering a question and the teacher following up with further question contains interrogative sentence (+0.2), clause complex (+0.2), and the first person plural (+0.1).

The process of teacher evaluation includes terminology (+0.1), interrogative sentences (+0.2), and imperative sentence (+0.4).

By extension, the entire lesson is organized based on the corresponding semantic block, with time as the x-axis and value as the y-axis. The data points are connected and a smooth curve is fitted using Excel.

During the process of obtaining the semantic wave and semantic context figure for the entire lesson, the focus is on analysing each semantic block within the teaching discourse. This approach enhances the understanding of teaching discourse for teachers or researchers, with their resulting insights being documented. The resultant semantic wave and semantic context figure provide teachers or researchers with a comprehensive and intuitive grasp of the entire class. The accompanying figure illustrates the corresponding relationship and time allocation between classroom activities and discourse. Furthermore, combining with coding notes and value assignments allows for reflection on how teaching discourse is expressed and organized in relation to its teaching context.

3.8 Triangulation

For qualitative research, triangulation is a significant instrument to guarantee the research validity and understandability (Denscombe, 2014; Denzin, 2012). This study primarily used methodological (between-methods) and data triangulation (use of contrasting sources of information) (Denzin, 1970). Figure 3.8 illustrates that triangulation was used to check accuracy of findings and provide a full picture of each lesson. Video material serves as a visual data source that dynamically illustrates the real-time interaction between semantic contexts and semantic waves, thereby facilitating the interpretation of teaching mainly via video observation. To gain

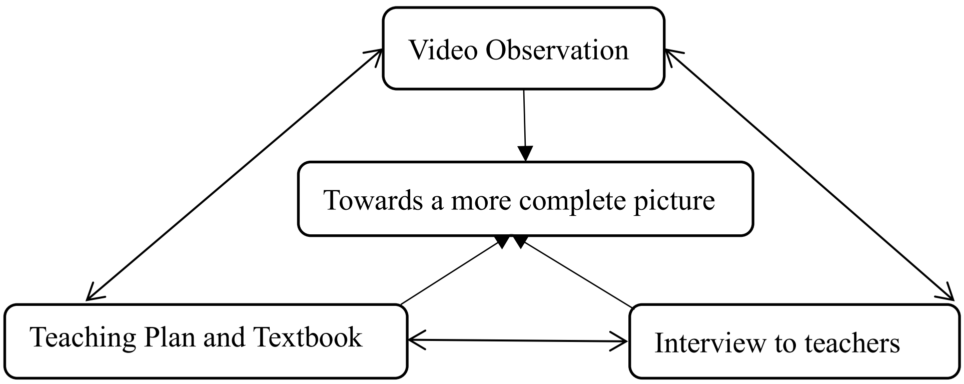


Figure 3.8 A diagram of Triangulation

insight into classroom teaching, video observation was used with other methods and sources of information. To exploit the benefits of between-methods triangulation, these other methods allow classroom teaching to be viewed from a contrasting angles (Denscombe, 2014). Therefore, this research included semi-structured one-to-one interviews. The research made use of written, document sources data. These were involved as an element of data triangulation. Teachers' plans and the textbooks provided contrasts to the findings emerging from videos and semi-structured interviews.

3.9 Ethical considerations

This research follows the British Educational Research Association (BERA, 2018) ethical guidelines for educational research. Before commencement of data collection, an email was sent to the university's School of Education Ethics Sub-Committee with a completed ethics form (Appendix 1.1). This research was conducted after receiving ethical approval (Appendix 1.2). The researcher needs to have solid theoretical grounds and empathy for participants. The researcher should recognise concerns relating to participants feeling vulnerable, and revise the content and communication style with them accordingly. The researcher removes and substitutes participants' names with pseudonyms in the thesis and data storage.

Informed consent obtained. Before the research, participants need to understand the research intentions. The participants are teachers. The research plan was explained. The volunteer teachers were asked for informed consent. Participants have the right to withdraw and quit the project at any time.

Open the research process to participants. The full plan of the research is explained in detail to the participant teachers so that they know how to assist in the research.

Respect the participants. It is necessary to show respect to teachers and their teaching. A prerequisite for research relationships is to gain trust, to enable sharing of opinions and ideas with the researcher. All classroom video and audio recordings are conducted with the consent of the teacher by researcher. Interviews will be conducted with the teacher's consent, and in cases where permission is granted, audio recordings will be made; otherwise, comprehensive notes will be taken. Remarks and conversations that are not publicly available to the teacher are deleted or edited.

Objective analysis and reporting. When reporting, the researcher must interpret information objectively to make content readable. A statement of limitations (section 6.6) in the study design is reported to enhance credibility.

3.10 Summary

This chapter provides a comprehensive overview of methodological considerations and concrete analysis methods employed in the study of physics classroom discourse semantic waves and contexts. The study employs a diverse range of methods to gather evidence and describe multiple semantic contexts, depict semantic waves, and demonstrate their relationship. These approaches are guided by critical qualitative research (section 3.3). Video analysis serves as the main method, supported by text analysis and semi-structured interviews for additional information. This enables an in-depth understanding of classroom discourse semantic contexts and how teacher PCK can be effectively applied to teaching practice. Teachers' PCK is derived from textbooks, lesson plans, and teacher interviews. Through detailed analysis of teaching videos, this study extract the PCK manifested in instructional practices while describing the corresponding semantic wave based on theoretical framework. By comparing the analysis results of samples and data sources, this study establish the relationship between semantic waves and context.

In the next two chapter, I will report the findings based on the theoretical framework in response to data types.

Chapter 4 Data Analysis: How did the teacher plan to teach?

We all need to prepare textbooks, prepare students, and prepare teaching methods, as we are taught in school. However, after working for a long time, we may inadvertently overlook certain steps and gradually develop our own teaching style.

-Oliver

4.1 Introduction

This chapter examines data from three sources: textbooks, teachers' teaching plans and teacher interview.

Textbooks serve as crucial resources for teachers, enabling them to comprehend curriculum standards and teaching concepts. Additionally, they are valuable learning materials for students, helping them to comprehend the significance and challenges in classroom learning. The teaching plan is the design and planning of classroom teaching content and objectives, time arrangement and teaching materials that contain teachers' concept of the lesson. The analysis of the teaching plan aims to explore the teacher's idea of teaching before class. The interview provides highlights the practical challenges encountered during its implementation, and offers valuable recommendations for addressing these issues from teachers' perspective. The analysis of these data provides answers to the first research question and its sub-questions:

RQ1. What is the semantic context of post-16 Chinese students' physics lessons?

The sub-questions are:

1.1 What are the scientific concepts and methods involved in the specific topic?

1.2 What are the students' situation that influences teaching?

1.3 What factors that influence instructional practices?

1.4 How do teachers handle these factors within teaching?

This chapter report findings with reference to PCK part of established theoretical framework.

The comparison of textbooks could help the researcher to have a preliminary concept of existing teaching. Considering that the teachers included in this research all used the People's Education Press (PEP) version textbooks, this research selects Chinese lower- and upper-secondary school PEP textbooks (CLT and CUT stand for Chinese lower- and upper-secondary school textbook respectively) (Peng, 2013; Zhang, 2007), and Assessment and Qualifications Alliance (AQA) Physics General Certificate of Education Advanced Level (A-level) textbook

(Breithaupt, 2015). The content contained in CLT could be regarded as the prior knowledge of upper-secondary school teaching content. The comparison of CLT and CUT could reveal the transfer of learning outcome and the evolution of knowledge points in CUT, which would be the focus of teacher teaching. Comparing CUT and AQA may disclose ways of presenting the same content, exploring the important and difficult concepts in textbooks and providing plentiful teaching materials for teaching. This chapter compares and establishes connections in the four aspects of language expression (section 4.3.1), content knowledge structure and requirement (section 4.3.2), and scientific method presentation (section 4.3.3) of the three versions of physics textbooks. Seventeen teaching designs according to topics (Topic M - section 4.4.1, Topic F - section 4.4.2, and Topic E - section 4.4.3)were analysed and compared. Section 4.5 shows the results of teacher interviews analysis carries out analysis from three aspects of physics knowledge (section 4.5.1), knowledge of students (section 4.5.2) and instructional strategy (section 4.4.3). The analysis process is discussed in methodology chapter section 3.7.

To study classroom discourse more deeply, it is necessary to analyse each specific teaching behaviour in the specific context of the entire class. Section 4.2 presents the information of teachers and the classes as the background of the lesson.

4.2 Information about the teachers and students

Based on interviews with teachers and official introduction information from the school, this section introduces basic information about teachers and the classes taught in their videos.

4.2.1 *Teachers and classes in topic M*

Table 4.1 Basic information about the Topic M teachers' original schools

School	Province**	established in	Ranking*	The total area of the school (m^2)	The number of class
Jack's school	Anhui (679)	1958	4% (2%)	100201	30
Lily's school	Liaoning (431)	1962	4% (3%)	17200	24
Sophia's school	Xinjiang (300)	1978	1% (1%)	90667	36
Leo's school	Liaoning (431)	1948	5% (11%)	73000	36
Oliver's school	Sichuan (806)	1940	1% (1%)	44666+112000	67

(Data source is the website of the Ministry of Education of China public information and the official websites of corresponding schools)
*Gaokao performance among China, (Gaokao performance among the province that school located in). There are 14585 upper-secondary schools in China .
** The provincial distribution map is shown in Figure 3.2 The distribution of teachers' original location included in Chapter 3 section 3.5. The value represents the number of regular upper-secondary schools in the area

Jack comes from a top 4% upper secondary school in China, and the top 2% upper secondary school in Anhui province in the 2019 ranking. The position of the ranking indicates that the admission score of the school is almost the highest locally, and teacher resources and financial assistance are sufficient. The school was formerly established in 1921 as a secondary vocational school; in 1958, it was identified as a key secondary school in Anhui Province. In 1978, it was one of the first nine key secondary schools in Anhui Province. It was rated as one of Anhui exemplary schools in 2000. In 2010, it moved to a new location in a new district of Anhui Province. The total area of the school is 100201 m^2, and the green area is 14547 m^2; there are 60 classes (20 grade 10 (aged 16) classes, 20 grade 11 (aged 17) classes and 20 grade 12 (aged 18) classes) involving more than 3700 students and 268 teachers. The number of students was above the national average of 1800 students (MoE, 2019a, 2019b). Most students are Anhui natives. A small proportion of students transfer from other provinces to this school, because of their parents' job transfer.

Jack is the physics leading teacher in his school, responsible for organising all the physics teachers to carry out teaching and research activities including formulating teaching progress, examination time and scope, or solving the doubts generated by teachers in teaching. He has an upper secondary school physics teacher qualification with a bachelor degree in Physics (Teaching). He has been a teacher for ten years in the same school. His students believe that Jack is regarded as being the best physics teacher in their school; his relationship with the students is characterised by a 'strict', responsible and very caring approach. In class, he consistently offers encouragement and praise to the students while laying down clear and firm expectations about behaviour which focus on their attainment in physics.

As discussed in section 3.5, Jack and other six teachers (Lily, Sophia, Ava, George, Oscar and Charlie)' Good Lesson are recorded in Beijing teaching pre-arranged groups of 20 students, as part of the national project. ***Jack's class*** for the study was a Year 11 group of twenty students (fifteen boys and five girls) aged 16-17 years. The lesson was taught in Beijing as a show class (detailed information shown in 1.1.4). The class comes from a top 2% upper-secondary school (S school) in China, and the top 4% in Beijing (332 schools in total). S school is a mixed-gender school, which enrols students, aged 11 to 18. At the time the show class recorded, approximately 2000 students aged 16 to 18 years and 1200 aged 11 to 16 years were on a roll. The number of students was above the national average of 1800 students. Most students were Beijing natives, and approximately 300 students were international students or Hong Kong, Macao and Taiwan students. S school was built up in 1956 and is an exemplary school in Beijing.

Historically, students perform well in Zhongkao and Gaokao locally. The enrolment rate of the school is 100% in recent years, and almost all graduates may go to a key university. As Jack said, it would be fair to say that the majority of students in the class would be higher than the national average of ability, and even better than his students in learning outcomes (M1-I). As regards behaviour, the class had a reputation in the school for being 'lively'. Many students have the self-discipline to buckle down and focus when seating in a classroom and was able to master learned knowledge, and even some students will self-study in advance.

The lesson is taught in a room that is dedicated to recording lessons. The organisation of desks and chairs are set out in a group format with the teacher's demonstration desk at the front of the room and the students sitting in a group of five facing the front.

Lily's class and **Sophia's class** are similar to Jack's. They were taught in the same school in Beijing and are a Year 11 group in which there are 20 students aged 16-17 years. The attainment of students is comparable with Jack's class. The only differences are the proportion of male and female students and seat arrangement. In Lily's class, there are 11 boys and 9 girls setting out in a group of five formats. In Sophia's class, 6 boys and 14 girls sit in rows facing the front with two students sit together (shown in Figure 4.1).

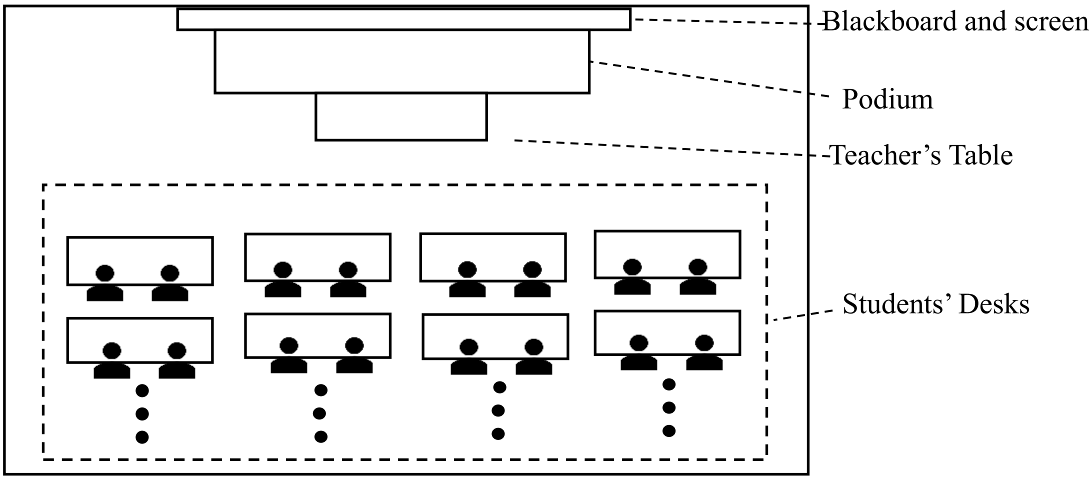


Figure 4.1 A diagram of classroom organisation

Lily and **Sophia** are young female teachers. Compare to Jack, they are in the introductory stage of their teaching career. The teachers are popular among students, and they work hard. In addition to regular teaching work, the two teachers actively participate in various open classes to improve their teaching skills. Their instructional designs heavily influenced by other teachers' design they have not formed a significant personal style. For example, Sophia imitated Leo's teaching design. Before participating in this competition, she rehearsed the Good Lesson she taught in the national project 8 times in her class, and she practiced her teaching draft repeatedly in private. The teaching languages of them can already illustrate their styles. In the teaching implementation, Sophia pays attention to the fluency of language and rhythmic consistency of the course. Lily repeats key content, paying attention to the scientific nature of the language, and prefers to professionalize the students' daily language.

Leo is a senior teacher of physics in upper-secondary school and he stands out as an exemplary educator with exceptional teaching proficiency locally. He is currently leader of the Physics Teaching and Research Group of his school, a tutor of postgraduate students at the local Normal University, and a member of the local Physics teacher Studio. He has administrative duties. ‘Teacher, preaching, teaching, and solving puzzles.’ This is a well-known old saying that he never forgets. He is deeply aware that to be a competent teacher, you must first correct yourself and then correct others; you must improve and enrich yourself first, and then be a teacher of others. The learning atmosphere in his school is relaxed and free, and there are plenty of extracurricular activities. He doesn't put academic performance first. He often tells students: 'If you got a bad result in an exam, that's ok. You will have a lot of bad exams in the future! I'm not discouraged, you just want to give up treatment(‘treatment’ is a Chinese meme, the last sentence means ‘I won't leave you hanging, and you can't give up on yourselves’)? ' Most students in the school have average grades or are high achieving students who ‘failed’ the upper-secondary school entrance examination.

Oliver is a senior teacher of physics in upper-secondary school and a key teacher locally. He believes that every child is a potential genius, therefore, the art of teaching is not about imparting knowledge, but about awakening and motivating. What he conveyed to the students is to do everything steadily and live happily every day. The school is a prestigious school with a long history, and the students naturally have excellent academic performance.

4.2.2 *Teachers and classes in topic F*

Table 4.2 Basic information about the Topic F teachers’ original schools

School	Province	established in	Ranking*	The total area of the school (m^2)	The number of classes
Charlie's school	Jilin (263)	1948	4% (2%)	100000+14000	76
Ava's school	Sichuan(806)	1957	1% (1%)	200000	156
George's school	Jiangxi (544)	1941	4% (4%)	153334	88
Oscar's school	Zhejiang (631)	1953	5% (8%)	246667	65
Freddie's school	Jiangsu (609)	1943	4% (9%)	156667	60

(Data source is the website of the Ministry of Education of China public information and the official websites of corresponding schools)
*Gaokao performance among China, (Gaokao performance among the province that school located in). There are 14585 upper-secondary schools in China .
** The provincial distribution map is shown in Figure 3.2 The distribution of teachers’ original location included in Chapter 3 section 3.5. The value represents the number of regular upper-secondary schools in the area

Charlie's, Ava's, George's and Oscar's classes are similar to Jack’s, Year 11 group from the same school in Beijing comprising 20 students aged 16-17 years. The attainment of students is comparable with Jack’s class (section 4.2.1).

Charlie is an excellent class teacher and the deputy director of the political and education office of the school. His teaching philosophy is that love is the foundation of successful teaching, and innovation is the hope of education. **Ava** is a young teacher and her school is the largest compared with other schools, Table 5.3 only shows the area of the school district Ava located during this research interview. Ava’s school has five school district. Young teachers move between school districts, enabling them to engage with a larger student population and access more abundant educational resources. **George** has 10 years of teaching experience. A seasoned senior teacher with extensive experience assisted him in formulating and refining the instructional plan. George has been relocated to another educational institution in pursuit of enhanced academic opportunities subsequent to his participation in this study. **Oscar** has worked as a teacher for eleven years, and he has shifted his work focus to administration before his participation in this study. Oscar is deputy director of the school affairs coordination centre responsible for school resource integration, the formulation of comprehensive plans, and the establishment of development strategies. **Freddie** has ten-year teaching experience, and he is the local subject leader (physics).

4.2.3 *Teachers and classes in topic E*

Table 4.3 Basic information about the Topic E teachers’ original schools

School	Province	Established in	Ranking*	The total area of the school	The number of class
Ivy's school	Liaoning (431)	1995	3% (2%)	46165	65
Mia's school	Liaoning (431)	1952	5% (11%)	110000	57
Emily's school	Liaoning (431)	1948	5% (11%)	220000	90
Ella's school	Liaoning (431)	1910	7% (12%)	94000	48
Daisy's school	Liaoning (431)	1946	6% (12%)	36000	36
Hannah's school	Liaoning (431)	1946	6% (12%)	36000	36
Luna's school	Liaoning (431)	1952	5% (10%)	120000	25

(Data source is the website of the Ministry of Education of China public information and the official websites of corresponding schools)

*Gaokao performance among China, (Gaokao performance among the province that school located in). There are 14585 upper-secondary schools in China .

** The provincial distribution map is shown in Figure 3.2 The distribution of teachers’ original location included in Chapter 3 section 3.5. The value represents the number of regular upper-secondary schools in the area

Teachers of Topic E are younger than the teachers of Topic M and Topic F. Teachers of Topic E are all from Liaoning province, and they often hold teaching seminars and lesson study together. These seven teachers are female; in upward periods of their careers; have families to care for and do not have administrative work.

4.3 Physics content and teaching suggestions in the textbook

Textbooks and curriculum standards are main resources for teachers in planning their teaching. In China's highly centralized educational system, educational staff have limited decision-making power when deciding teaching matters (Peng, 2009). Within such a climate, textbooks and curriculum standards in all subjects are developed by the national centre for school curriculum and textbook development under the Ministry of Education's authorisation (MoE, 2017b). Furthermore, '[t]*he transmission of scientific knowledge ... relies heavily on the advanced textbook*' (Giere, 1988, p. 62). Therefore, it is essential to introduce the content and requirements of the textbook and curriculum standards as crucial background information.

In particular, organisation and presentation of the core content significantly influence the design and implementation of teaching. Analysis of textbooks is helpful to understand the physics teaching problems from one side, especially the impact of the presentation of textbooks on physics teaching (discussed in section 3.7.3). As introduced in section 4.1, the following sections report the analysis result from four aspects of language expression (section 4.3.1), content knowledge structure and requirement (section 4.3.2), and scientific method presentation (section 4.3.3) with the comparison between textbooks.

4.3.1 *Language expression in the textbooks*

This section aims to analyse the language used in physics textbooks (CLT, CUT and AQA) that tends to project teaching information. The texts of the textbook are divided into units according to concepts. All units are analysed from two considerations, *formality* (Halliday & Martin, 1993) and *framing* (Bernstein, 2003a) (discussed in section 2.2.4).

Formality

The language formality of CLT is the lowest among the three. The sentences do not incorporate symbols, equations, or intricate nominal groups and favours the utilization of verbs in an active voice and concise sentence structure. The formality of CUT is lower than that of AQA (Table 4.4). The results of another study confirmed the trend of increasing complexity and specialisation of language codes in textbooks as education levels improved, which found that the same trend exists in Greek science textbooks (Korfiatis, Stamou, & Paraskevopoulos, 2004). CUT rarely uses nominal groups and complicated clauses. Instead, it uses parataxis sentences and simple sentences.

Between education levels, CLT is lower in specialisation and rigour than upper-secondary school textbooks. Whether it is CUT or AQA, most of the expressions are highly specialised and rigorous. Improving students' mastery of specific terminology and understanding their internal logic is what upper-secondary school needs to do as a transitional stage from lower-secondary school to college.

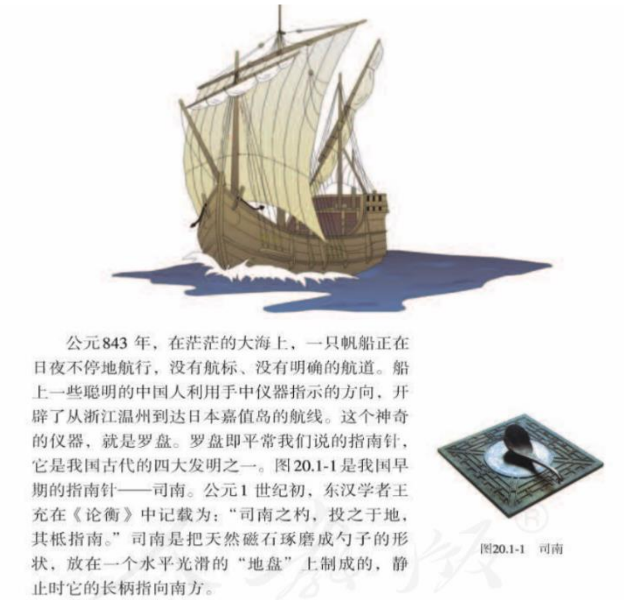

公元843年，在茫茫的大海上，一只帆船正在日夜不停地航行，没有航标、没有明确的航道。船上一些聪明的中国人利用手中仪器指示的方向，开辟了从浙江温州到达日本嘉值岛的航线。这个神奇的仪器，就是罗盘。罗盘即平常我们说的指南针，它是我国古代的四大发明之一。图20.1-1是我国早期的指南针——司南。公元1世纪初，东汉学者王充在《论衡》中记载为："司南之杓，投之于地，其柢指南。"司南是把天然磁石琢磨成勺子的形状，放在一个水平光滑的"地盘"上制成的，静止时它的长柄指向南方。

图20.1-1　司南

Figure 4.2 The introduction of magnetic field and magnetic phenomena in CLT
(Peng, Q., 2013, p. 120)

Example 1 *(Figure 4.2) In 843 AD, in the vast sea, the sailing boat was sailing day and night, without beacons and clear channels. Some intelligent Chinese on board found the directions indicated by the instruments in their hands. They opened a route from Wenzhou, Zhejiang, to Jiazhi Island, Japan. This magic instrument is the Luopan. The Luopan is the compass we usually say. It is one of the four great inventions in ancient China. In the early 1st century AD, Wang Chong, a scholar of the Eastern Han Dynasty, wrote in 'On Balance' that, 'Sinan's spoon is cast on the ground, and its handle points the south.' Sinan is made by cutting a natural magnet into the shape of a spoon and placing it on horizontally smooth ground. Its long handle points to the south at rest. (CLT-E)*

The form of Example 1 in CLT exhibits a narrative style, devoid of specific terms or intricate syntactic constructions. Adjectives are employed extensively not for noun definition but rather to convey descriptive and figurative elements. All sentences adopt concise and straightforward structures. This excerpt delineates a scenario while providing introductory insights into pertinent knowledge.

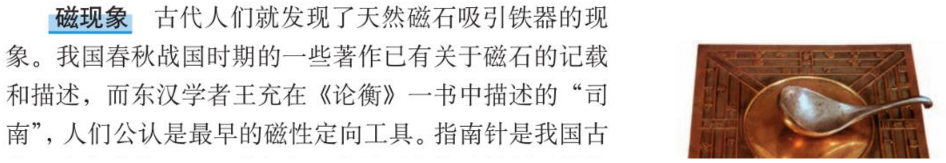

磁现象　古代人们就发现了天然磁石吸引铁器的现象。我国春秋战国时期的一些著作已有关于磁石的记载和描述，而东汉学者王充在《论衡》一书中描述的"司南"，人们公认是最早的磁性定向工具。指南针是我国古

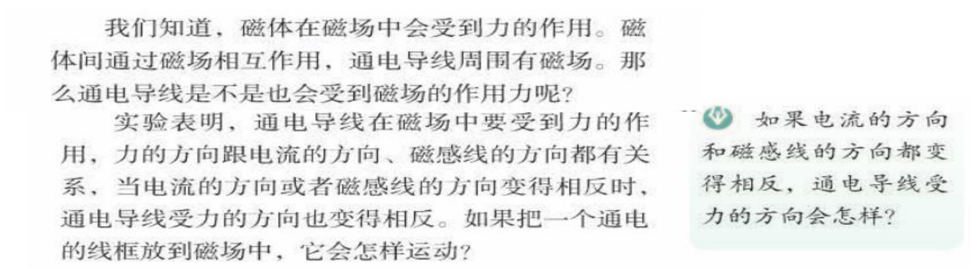
Figure 4.3 The introduction of the magnetic field and magnetic phenomena in CUT
(Zhang, 2007, p. 80)

Example 2 *(Figure 4.2)* ***Magnetic phenomena****: In the Spring-Autumn and Warring States Periods, some works already have records and descriptions of magnets in our country. The Eastern Han scholar Wang Chong's 'Sinan' described in 'On Balance' is widely recognised as the earliest <u>magnetic orientation tool</u>. The compass is one of the four great inventions in ancient China. At the beginning of the 12th century, our country had a clear record of the compass used for <u>navigation</u>. (CUT-M)*

Example 3 *Magnetism is a topic with a long scientific history stretching back thousands of years when lodestone was used by explorers as a navigational aid. Over the past 50 years or so, scientific research has led to many applications such as particle accelerators, powerful microwave transmitters, magnetic discs and tape, superconducting magnets, and magnetic resonance scanners. Magnetism is a valuable scientific tool used by archaeologists, astronomers, and geologists. In short, magnetism has always been a fascinating topic and continues to be so. (AQA-M)*

(Breithaupt, 2015, p. 396)

On the contrary, Example 2 and 3 from CUT and AQA involve specific terminology; however, nominalization or passive voice expressions are absent. Although sentences in these examples exhibit a slightly higher level of complexity compared to Example 1, they still maintain a low degree of language formality.


我们知道，磁体在磁场中会受到力的作用。磁体间通过磁场相互作用，通电导线周围有磁场。那么通电导线是不是也会受到磁场的作用力呢？

实验表明，通电导线在磁场中要受到力的作用，力的方向跟电流的方向、磁感线的方向都有关系，当电流的方向或者磁感线的方向变得相反时，通电导线受力的方向也变得相反。如果把一个通电的线框放到磁场中，它会怎样运动？

如果电流的方向和磁感线的方向都变得相反，通电导线受力的方向会怎样？

Figure 4.4 The force on a current-carrying wire in a magnetic field (CLT-F) (Peng, Q., 2013, p. 133)

Example 4 *(Figure 4.4) We all know that magnet would experience a force when placed in a magnetic field. The magnets interact with each other through the magnetic field, and there is a magnetic field around the current-carrying wire. So, are current-carrying wires experiencing the effect from the magnetic fields?*

The experiment shows that the current-carrying wire experiences force in the magnetic field. The direction of the force is related to the direction of the current and the magnetic field line. When the current or magnetic field line direction becomes opposite, the direction of the force applied on the current-carrying wire becomes opposite…

The language in Example 4 is scientifically specialised (strong classification) since its generation is based on an experiment that gives specific characteristics to the language.

Example 5

The two most attractive parts of the magnet are called magnetic poles. (CLT-M)

(Peng, Q., 2013, p. 120)

Each part of the magnet has different magnetic strength, and the region of a magnet where *the external magnetic field is strongest is called the magnetic pole.* (CUT-M)

(Zhang, 2007, p. 80)

The language expression of the introduction part in CUT is like an abbreviated version of the same part in CLT without many changes in formality and framing. The definition of knowledge points in CUT is more detailed than in CLT (example 5). The following two sentences are the definition of magnetic pole written in the lower and upper secondary school textbook.

In Example 5, The first definition gives a fact without extra explanations. The second sentence gives detailed information 'each part of the magnet has different magnetic strength', forming a complete logical meaning with the other clause. The first clause indicates that somewhere should be the strongest region. Then, the following clause tells that the region is called the magnetic pole.

Among the various topics, it can be observed from Table 4.1 that topic M exhibits a relatively lower level of formality compared to topics F and E. The knowledge presented in topic M predominantly serves as an introduction, resulting in reduced language complexity. However, when dealing with definitions, equations, and calculations in topics F and E, it becomes imperative to employ linguistic intricacy to enhance the scientific professionalism of the discourse while maintaining conciseness.

Framing

The majority of textbooks exhibit a weak framing, with declarative sentence type and third singular, plural person or nominal group as person pronouns. There are minimal disparities observed between different versions and topics at the educational level (Table 4.4). The majority of textbooks exhibit a weak framing, with declarative sentence type and third singular, plural person or nominal group as person pronouns. There are minimal disparities observed between different versions and topics at the educational level (Korfiatis et al., 2004). The core focus in the CUT lies on Ampère force, which necessitates a considerable amount of spatial intelligence to differentiate it from electric field (Peng, 2009). Thus, the language narrows the space down for students in F of CUT, with imperative sentence type and the first person plural (We) as person pronouns.

These explanations are based on language expression and curriculum documents. The way teachers deal with language in teaching is analysed in section 5.2 and the following section 4.4 and 4.5 through the teacher's instructional design and reflection.

Table 4.4 Formality and Framing level of the Science Textbooks

Versions of textbook	Topics	Formality			Framing	
		High	moderate	Low	Strong	Weak
Chinese lower-secondary school physics (CLT) (Peng, 2013)	Magnetic phenomena and magnetic field (M)	-	-	Magnetism, Oersted's experiment, Magnetic field, The Earth's magnetism	-	Magnetism, Oersted's experiment, Magnetic field, The Earth's magnetism
	Force on a current-carrying wire in a magnetic field (F)	-	-	The principle of electric motor	-	The principle of electric motor
Chinese upper-secondary school physics (CUT) (Zhang, 2007)	M	-	-	Magnetism, Oersted's experiment, Magnetic field, The Earth's magnetism	-	Magnetism, Oersted's experiment, Magnetic field, The Earth's magnetism
	F	-	Ampère force	Magnetoelectric ammeter	Ampère force	Magnetoelectric ammeter
	Electric field strength (E)		Electric field strength	Electric field, Electric field line, Uniform electric field	-	Electric field, Electric field strength, Electric field line, Uniform electric field
AQA physics A-Level (AQA) (Breithaupt, 2015)	M	-	Magnetic field	Magnetism, The Earth's magnetism	-	Magnetism, magnetic field, the Earth's magnetism
	F	The force on a current-carrying wire in a magnetic field, The couple on a coil in a magnetic field	-	-	-	The force on a current-carrying wire in a magnetic field, The couple on a coil in a magnetic field

Versions of textbook	Topics	Formality			Framing	
		High	moderate	Low	Strong	Weak
	E	Static electricity, Electric field strength, The electric field between two parallel plates, Field factors	Field lines and patterns	-	-	Static electricity, Field lines and patterns, Electric field strength, The electric field between two parallel plates, Field factors

4.3.2 *Knowledge structure and requirements*

The fundamental components of the subject matter in physics consist of concepts and laws. Physics concepts embody the essential characteristics of material entities and are integral to comprehending this field. Meanwhile, physics laws elucidate how relevant concepts interrelate within specific physical states or processes under particular conditions. Beyond these elements, teaching content encompasses both practical applications of these principles and observable phenomena in physics. Therefore, when studying pedagogy related to physics knowledge acquisition, it is imperative to scrutinize textbook presentations alongside teacher preparation and student learning strategies.

The presentation of the three topics in the three textbooks is categorised into concepts, rules and applications, as shown in Table 4.5. The three textbooks contain similar physics, there are discrepancies in laws, phenomena and applications.

Table 4.5 Knowledge classification contained in three textbooks

Versions of textbook	Topics	Physics concepts	Physics phenomena and applications	Physics laws
CLT	M	1. Magnetic field, 2. Magnetic induction line	1. Magnetic phenomena, 2. Animal navigation, 3. The Earth's magnetism, 4. The magnetic effect of current, 5. Magnetic field around an energized solenoid 6. Electromagnet, 7. Electromagnetic relay	Ampère's rule
	F	The force on a current-carrying wire in a magnetic field	1. The electric motor 2. Speaker	-
CUT	M	1. Magnetic field, 2. Magnetic induction line	1. Magnetic phenomena, 2. The magnetic effect of current, 3. The Earth's magnetism, 4. Compass and navigation	-
	F	Ampère force	1. Magnetoelectric ammeter, 2. Spinning liquid	Left-hand rule
	E	1. Electric field, 2. Electric field strength, 3. Electric field line, 4. The electric field around a point charge 5. Uniform electric field	Faraday and Field	Field strength superposition principle
AQA	M	1. Magnetic field, 2. Line of force	1. Magnetic phenomena, 2. The Earth's magnetic field	-
	F	The force on a current-carrying wire	The electric motor	Fleming's left-hand rule
	E	1. Electric field strength, 2. The electric field between two parallel plates 3. Field factors	The lightning conductor	-

The physics concepts contained in M focus on magnetic fields and magnetic induction lines. The representation of magnetic induction lines varies between AQA and Chinese teaching materials, namely as ‘line of force’ and ‘magnetic induction lines’. In 1983, the old Chinese upper-secondary physics textbooks used the term, ‘line of force’, which is the same expression as in the AQA textbook. In 2003, after the textbook was revised, the term was changed to ‘magnetic induction lines’, which are used until today. Faraday established a physics framework cantered around the concept of force, which included the term ‘line of force’. Subsequently, Maxwell referred to this as the ‘line of induction’. Consequently, these two concepts share broad similarities; however, it is important to note that the notion of ‘force’ in the ‘line of force’ does not align entirely with Newton's classical mechanics. The latter is the foundation of the physics system established for Chinese upper-secondary school students. This is why Chinese textbook using ‘magnetic induction lines’ instead of ‘line of force’. Students exposed to electromagnetism inevitably associate ‘line of force’ with ‘force’. Chinese textbook editors opted for magnetic induction lines to alleviate potential difficulties (Li, C., 2015). However, the expression splits the relationship between the force and the magnetic induction line, and is not conducive to cohesion with the college physics content.

The physics concepts contained in Topic F are similar, and there are different expressions of concepts. CUT refers to ‘the force on a current-carrying wire in a magnetic field’ as Ampère force. Ampère force refers to the force of attraction or repulsion between two wires carrying currents specifically. CUT expands the meaning of Ampère force.

The basic concept range of Topic E has a considerable discrepancy. AQA adds an extension point, field factors instead of the prior knowledge; the electric field and point charge are all in separate sections. The CUT puts electric field and electric field lines into this lesson, hoping to form a complete system from the structure. Coulomb’s law is prior knowledge for E in CUT and follow-up knowledge for E in AQA. This difference in content organisation leads to E, for Chinese teachers, a vast topic that contains interrelated knowledge that requires mathematical derivation. According to the situation of the students, the teacher should modify appropriately and connect the parts reasonably. In section 4.4.3, the teacher's teaching design in this study is analysed to investigate teachers’ teaching approaches.

Within the same topic, the number of phenomena and applications involved in CLT is the most, and AQA is the least. In the each textbook, M is the most and E is the least. The secondary school textbooks start from everyday life and introduce more applications and phenomena. The scientific and rigorous nature of the concepts presented in high school textbooks surpasses that of middle school materials, confirmed by the previous section's language analysis. From this perspective, AQA is more professional than CUT, with a greater conciseness of language and the incorporation of additional conceptual connotations and extensions; Topic E is more professional than Topic M and Topic F. AQA and CLT take the electric motor as the primary application example in Topic F. The electric motor principle is used to expand the force on a current-carrying coil in a magnetic field. In this part, CUT explained with another application, electromagnetic ammeter as a model, and a small experiment of spinning water is added.

In Topic M, Ampère’s law is the law mentioned by CLT, used to judge the magnetic field polarity generated by the current-carrying solenoid. CUT and AQA do not mention it. In Topic F, CLT introduces concepts, as applications and phenomena do not involve the laws. CUT and AQA introduce the left-hand rule, and there are differences in the expression. AQA introduced Fleming’s left-hand rule, and CUT introduced the simplified version of Fleming’s left-hand rule (Li, C., 2015). The left-hand rule proposed by CUT is not ideal in the embodiment of physics laws. Fleming’s left-hand rule reflects the spatial relationship between the three physics quantities, magnetic induction (B), current (I) and force (F). The corresponding right-hand rule in American textbooks emphasises that the force is perpendicular to the plane formed by the current and magnetic induction line (Zitzewitz, 2005). The left-hand rule in the CUT is a simplified version of Fleming’s left-hand rule; it cannot reflect the force is perpendicular to the current and perpendicular to the magnetic induction line (Ren, 2017).

The presentation of basic concepts and laws reflects one aspect of the presentation of physics knowledge. The content should cover concepts and laws required in the curriculum standards. The upper-secondary school physics discipline should develop students’ ability to use these concepts and laws to solve specific problems and explain related physical phenomena. Therefore, rich application examples and physics phenomena are set in Chinese school physics textbooks to consolidate students’ understanding of concepts and laws. Through various examples and phenomena, students are broaden their thinking to solve problems. These phenomena and examples are not necessarily suitable for the life background of all students. Would teachers adjust teaching design and teaching process or follow the original teaching materials? The next section 4.4 analyses how the teachers who participated in this study used the teaching materials to plan and implement the lessons.

In summary, through the analysis of the presentation of concepts, laws, and related physics phenomena in the three textbooks, we see that the knowledge points of CLT and CUT are similar, and the differences exist in the specialisation of the language, as well as the physics phenomena and applications cited. CUT simplifies the corresponding physics knowledge according to students' understanding ability to reduce the difficulty of understanding. AQA's knowledge incline towards the expertise and extension of knowledge. Whether these simplifications in CUT achieve the purpose of simplification is questionable among some teacher-researchers (Li, C., 2015; Ren, 2017; Yang, 2020).

4.3.3 *Scientific methods and reasoning*

Among the three topics examined in this study, the physics concepts, laws, and related applications discussed in the section 4.3.2 are explicitly presented in textbooks. In addition to these explicit contents, there exists a crucial yet often overlooked or implicitly present aspect within electromagnetism and even physics subject content – namely, the methods and reasoning employed. Zhang (2011) succinctly outlined the guiding principles of the scientific method, emphasizing that concepts or their interconnections should embody the essential elements of scientific methods during their establishment, extension, and expansion processes. These methods and reasoning are utilized for studying concepts, summarizing laws, describing phenomena, and conducting experiments. Although explicit content knowledge differs from implicit scientific methods, they are inseparable (Zhang, 2011). The physical methods are the connection to the establishment of knowledge, plays a vital role in establishing and applying physics concepts and laws. The physics methods are the intermediate link from knowledge learning to ability development, acting as a bridge to communicate between content knowledge and ability. They plays a vital role in the cultivation of students' scientific literacy.

Kind and Osborne (2017) discusses Styles of Scientific Reasoning based on the characteristics of physics and cognitive science, which provides a more cohesive and comprehensive schema for understanding scientific reasoning. The model fits well with this research and is the basis of this part of the analysis framework (discussed in section 3.7.3). The distinction between explicit and implicit in this section pertains to whether the text explicitly acknowledges the utilization of specific scientific methods or reasoning. Text that explicitly acknowledges the use of scientific method and reasoning is referred to as an explicit presentation, while text that does not is classified as implicit. Table 4.6 shows the distribution of science methods based on the styles of scientific reasoning (Examples of six reasoning styles presented in the text are shown in the Appendix 6).

Table 4.6 The presentation of scientific methods and reasoning in textbooks

Versions of textbook	Topics	Scientific methods and reasoning*	The way pf presentation (Explicit/Implicit)
CLT	M	E: to evaluate the direction of the magnetic field; E and HM: to verify the current generating magnetic field; E and HM: to evaluate the magnetic field around the current-carrying solenoid; C and HM: to introduce the Ampère’s rule; E: to explore magnetic field factors	Explicit; Explicit and implicit; Explicit and implicit; Implicit; Explicit
	F	E: to evaluate the force on the current-carrying wire and coil in a magnetic field	Explicit
CUT	M	HB and C: to comb the magnetic phenomena; HB: to comb the discovery process of the earth's magnetism; HB: to comb the development of the magnetic effect of current	Implicit; Implicit; Implicit
	F	E: to explore the direction of Ampère force; M: to deduce the equation of Ampère force	Explicit; Implicit
	E	M, HM and E: to explore and deduce the equation of electric field strength; HM: to set up an ideal model - test charge; M: to deduce the field strength superposition principle; E: to present the electric field line	Explicit; Implicit; Implicit; Explicit
AQA	M	-	-
	F	E and M: to evaluate the force on the current-carrying wire and coil in a magnetic field HM: to explore the principle of electric motor	Implicit; Implicit
	E	M: to measure the electric field strength; HM: to set up an ideal model - test charge; M: to measure the electric field between two parallel plates; HM and M: to explore the field factors	Implicit; Implicit; Implicit; Implicit

*M: mathematical deduction, E: experimental evaluation, HM: hypothetical modelling, C: categorisation and classification, P: probabilistic reasoning and HB: historical-based evolutionary (referring to the concept of Kind and Osborne (2017)'s reasoning style).

Based on the above analysis of the textbooks, hidden scientific methods and reasoning are found in the expression of physics knowledge. CLT uses explicit methods to present scientific methods and reasoning, directly telling students that we could obtain corresponding physics laws and concepts through experiments. Such explicit presentation of the method appears in the CUT; the implicit presentations are the majority. In contrast, the scientific methods contained in AQA exist implicitly. CUT's objective is to ascertain the underlying relationships rather than merely identifying its manifestation.

The physics methods and reasoning contained in textbooks for the same knowledge points are similar; although discrepancies remain. When CLT introduces Topic M, it introduced multiple experiments and guided students to establish hypotheses and physics models. Instead, CUT gives relevant physics concepts and the discovery process. CUT introduces the electric field strength equation, describing the mathematical deduction process of the electric field strength equation in detail, in conjunction with the experiment. CUT shows the ratio definition method used in this equation. AQA describes the relationship between the factors that affect the electric field strength and directly gives the equation. When discussing Topic M, CUT is based on theoretical prior knowledge written in CLT. CUT does not describe Topic M related knowledge by detailed materials; rather, the text provides the context of what happened and elaborates on the definitions (section 4.3.2). Teachers should unearth the scientific methods hidden in textbooks and flexibly apply appropriate scientific methods to classroom teaching according to the teaching contents and student characteristics.

The explicit reasoning process is conducive to improving students' performance in science learning (Lawson, Karplus, & Adi, 1978; Shayer & Adey, 1981, cited in Kind, 2013). Although the abstraction of physics methods and reasoning brings difficulties to its presentation in textbooks, as long as the appropriate methods are used, these scientific methods could be made explicit in teaching. Physics methods are as valuable teaching content as physics concepts. Because of their abstractness and covertness, teachers should pay more attention to them. To some extent, if knowledge content is a necessary accumulation of students' development abilities, then physics methods are the catalyst for achieving a qualitative leap in students' abilities. Concepts and methods are considered factors for teachers setting teaching goals, organising teaching content, and choosing teaching strategies. Therefore, teachers should actively use appropriate techniques to explore the hidden scientific methods in the textbook. In addition, according to the teaching content, teachers should consciously include physics methods into classroom teaching and guide students to pay attention to the physics methods and reasoning.

4.3.4 *Summary*

Similarities in the three textbooks exist. These include:

All three textbooks employ professional language, including proper nouns, formulas, and other technical terminology. The language is rigorous and concise, reflecting the academic nature of physics education. While CLT's content is relatively simple and story-oriented for lower-secondary school students, the two upper-secondary school textbooks (CUT and AQA) are more academic-worded and contain additional connotation and extension of concepts, formulas, diagrams, etc.. The frame of these three textbooks is weak. CUT provides a strong frame for describing Ampère force in Topic E. In CUT, the first person plural is used as the personal pronoun for numerous times, and imperative sentences are used to describe the left-hand rule in a commanding tone. In general, the three textbooks tend to use third person pronouns to state concepts and facts. The language expressions in textbooks are scientific, and leave room for teachers and students to understand and supplement (section 4.3.1).

The basic concepts included in the three textbooks exhibit similarities. In Topic M, all textbooks encompass the concepts of magnetic field and magnetic induction lines; In Topic F, they all address to Ampère force; whereas Topic E is exclusively covered by two upper-secondary school textbooks, namely AQA and CUT, which focusing on electric field and electric field strength. These basic concepts undergo certain modifications and adjustments across different versions of teaching materials to align with their respective instructional objectives. Furthermore, additional phenomena and applications are incorporated into the textbooks to facilitate students' enhanced comprehension and mastery of relevant concepts (section 4.3.2).

Experiments and hypotheses are encompassed within these textbooks. Scientific reasoning, as Kind and Osborne (2017) asserts, serves to fill in gaps in science education. An analysis of teaching materials reveals that reasoning permeates throughout the instructional content and intricately interconnects the concepts presented in each topic, thereby ensuring a comprehensive and logical coherence (section 4.3.3).

Differences include the language, as that in Chinese secondary school textbooks is concise relative to the AQA version. The complexity of language expresses semantic density and can be regarded as the degree of connection to advanced physics teaching content. Chinese textbooks use simple and easy-to-understand language, sacrificing connection with university physics courses.

Discrepancies in the content of physics phenomena and laws in the textbooks are apparent.

CLT encompasses a comprehensive range of physical phenomena, presented in clear and concise language, without an excessive use of terminologies. Compared with AQA, CUT adopts more basic concepts (e.g. electric field line, the electric field around a point charge, uniform electric field) and physics history (e.g. Faraday and Field) to assist students' understanding and appropriately broadens the extension of concepts, instead of adding more complex physical applications (e.g. the lightning conductor) that require knowledge integration to understand.

CUT joined historical-based evolutionary reasoning, which is a kind of patriotic education while introducing the origin of human exploration of knowledge. CUT and AQA add a mathematical deduction to topic F and topic E. These involve in-depth physics knowledge compared to topic M and require mathematical operations.

AQA does not put much space on the knowledge context introduction but focuses on explaining and applying knowledge and adding corresponding exercises. This point is lacking in CUT. Analysis of the semantic density of CUT, the content setting of CUT is biased towards CLT rather than AQA. CUT serves as an enhanced and complementary textbook to CLT, characterized by an expanded repertoire of concepts (section 4.3.2). However, it falls short in facilitating a profound comprehension of physics knowledge among students. In teaching, teachers should offer additional corresponding exercises and provide further elucidation based on the textbook content while establishing connections between these concepts to foster a comprehensive understanding of physics concepts.

In summary, the language employed in CLT is closely aligned with everyday language, aiming to convey physical concepts through historical narratives and phenomena. Both AQA and CUT serve as upper-secondary school textbooks, yet AQA adopts a more scholarly tone compared to CUT. The complexity of the language utilised in CUT is moderate across three textbooks. The incorporation of sentence type and personal pronouns within the language in CUT reflects its flexible framing, providing users with room for interpretation and engagement (section 4.4.1).

Secondly, *simplicity* exists in the description of knowledge and the summary of physics laws, leading to the divergences in knowledge from AQA. Researchers have argued whether this pursuit of language concision is effective (Li, C., 2015; Yang, 2020). CUT's main body mentioned numerous times that the establishment of corresponding models or extraction rules is aimed at the simplicity of memory or expression. Such simplicity sacrifices connection with the college physics content (section 4.4.2).

Thirdly, in the presentation of scientific methods and reasoning, CLT and CUT put experiments and demonstrations in a separate column, and write out ‘the experiment indicates that’ in the process of experimental analysis. The two textbooks clarify the derivation process of mathematics and summarise the mathematics-defined method. They present the process of hypothesis modelling and concept discovery and development. Scientific methods in AQA are presented implicitly. Explicitly elucidating scientific methods is conducive to students' learning; it should be noted that the explicit presentation of reasoning style in textbooks may not necessarily enhance students' learning. Textbooks serve as instructional materials, while the explicit exposition of scientific methods should take place during the teaching process. In CUT, emphasis is placed on explicit presentation, with highlighting the *experiment process and mathematical deduction*. Nevertheless, this explicit presentation is limited to merely naming the scientific method in order to provide students with a mnemonic device and establish a foundation for future learning; its effectiveness in facilitating students' comprehension of scientific reasoning and concepts remains unclear at present. Hence, there is an emphasis on doing exercises instead of the physics principles and laws contained (section 4.3.3).

Finally, there are *deficiencies in the organisation* of textbook content, which teachers should supplement during the teaching process. As scientific reasoning analysis appears in the textbooks, most space is used to introduce the experiments and mathematical deduction of concepts. It does not set the corresponding exercises following it, as AQA does, or introduce a large number of scenarios and applications as CLT does (section 4.3.3).

The concise language and concealment of scientific methods give teachers additional space to fill. They must formulate teaching plans according to students' knowledge and needs, and teachers' abilities, weighing the relationship between gravity and density, which include adding examples or exercises. Teachers may choose to continue to emphasise the importance of exercises or to analyse physics ideas.

To select teaching content, teachers should conduct a thorough comparison of textbooks, which includes the screening and organisation of teaching materials and language in accordance with specific instructional contexts. The application or phenomena of the same concept or law or the physical phenomena based on a concept and law could be an abstract physics situation or natural physics phenomenon with problems closely related to technology, production, and life. In textbooks, scientific methods and reasoning are intricately intertwined and subtly embedded within the intellectual content. However, due to teachers' limited attention to scientific methods and reasoning, there is a tendency for scientific methods to be overlooked in the teaching of upper-secondary school physics.

Physics teaching, especially teaching physics concepts and laws, should occur according to students’ exposure to, understanding of, and application of knowledge. The textbook is a significant reference and basis for teaching and learning, which should follow the same order to present concepts and laws. In this regard, CUT has deficiencies. If teachers want to teach based on textbooks, they should dig and analyse the textbooks from various angles to achieve optimal use. Additionally, even if a comprehensive understanding of the teaching materials is achieved, the teacher cannot rely entirely on textbooks as the only teaching material.

The teaching content could not be immutable. Teachers should pay attention to various materials and the connection between physics and life, production, technology timely. It could bring those current and real physics phenomena and applications into the classroom, build a bridge from physics exercises to the physics world for students, and help students complete a smooth transition from ‘being able to do physics exercises’ to ' understanding physics’.

How do teachers do it? The next section explores how teachers design and organise teaching content before class by analysing the teacher's teaching plan.

4.4 Teaching plan

This section conducts a textual analysis of the teacher's lesson plan, categorizing it into three parts based on physics topics (4.4.1 topic M, magnetic phenomena and magnetic field; 4.4.2 topic F, force on the current-carrying wire in a magnetic field; 4.4.3 topic E: electric field strength). Each part presents a comparative analysis of the suggested teaching process from the teacher's teaching book, and the teachers' teaching design. The objective of this section is to identify their respective characteristics, compare similarities and differences in teaching designs, thereby addressing research question one and obtaining corresponding teaching processes, teaching objectives, and areas requiring teachers' attention.

4.4.1 *Topic M: magnetic phenomena and magnetic field*

Magnetic field and electric field are the core content of electromagnetics in upper secondary school physics (Ke & Ma, 2016; Peng, 2009; Zhang & Yuan, 2019). For teaching of magnetic field, teachers may used an analogy this content with the electric field. Using analogy consciously and appropriately helps students accept knowledge and develop students’ thinking ability (Mozzer & Justi, 2012; Peng, 2009). Taber (2013) highlighted the limitations of employing a teaching analogy in situations where students lack comprehension of learning materials. Yet Taber does not recommend an analogy, especially when students are familiar with the knowledge. Before this lesson, students had learnt basic knowledge in their lower-secondary school physics class. Students taught in this topic demonstrate high performance in physics. So using analogy may be useful. By integrating knowledge of magnetic and electric field, students naturally accept the concept of the electromagnetic field (Peng, 2009).

The nature of the magnetic field is the basis for learning electromagnetic knowledge (Ke & Ma, 2016; Peng, 2009). This topic introduces magnetic phenomena, magnetic effects and geomagnetic field based on relevant knowledge taught in secondary school (MoE, 2017b; Peng, 2009). It focuses on introducing Oersted's experiment and patriotism education with science history as the background, 'Compass and Zheng He's Voyages' (Peng, 2009).

In addition to helping students develop logical understanding of the concept, the focus is on the magnetic effect of current and formation of the concept of a magnetic field. When teaching the topic, demonstration experiments are recommended as an instructional activity (Peng, 2009). A foundation for further learning of physics is laid through a combination of summarising learnt knowledge and enhancing understanding from the perspective of science and humanity (Zhang & Yuan, 2019). The content of this topic contains rich humanistic connotations (Peng, 2009). For students with good basic knowledge, the teacher may integrate the topic of the force in the magnetic field with this lesson (Peng, 2009).

Table 4.7 summarises the suggested schedule of teaching about this topic mentioned in the Chinese curriculum standard, teacher's teaching book and textbook (CUT). This class belongs to an introduction lesson and a review lesson. It is called a review lesson because the knowledge in this lesson coincides with the corresponding content in CLT in which the expansion of concepts and the enhancement of specialisation (section 4.3.2) are presented. In AQA, this lesson is an introduction part of the topic F and briefly introduced in a limited space (Appendix 6).

Table 4.7 Suggested teaching schedule about topic M, magnetic phenomena and magnetic field

Prior knowledge: basic electromagnetism			**Time taken:** 1 lesson
Learning objective	**Learning outcome**	**Learning activity with the opportunity to develop skills**	**Resources**
•Magnetism: the ability to attract metallic objects. •Magnetic pole: the region of a magnet where the external magnetic field is strongest. •Magnetic field: an invisible but objective substance which would give force to the magnetic or electric materials placed in it. •Magnetic lines never cross; the density of field lines indicates the strength of the field; could indicate the direction of the field; they always make closed loops. • Magnetic effect of current: Oersted's experiment; Ampère's rule. •Earth's magnetic field.	i) Understanding the magnetic effect of current. Through this class, the student could understand the discovery process of the magnetic effect of current, and realise the significance of Oersted's finding. ii) Knowing the basic characteristics of the magnetic field. iii) Understanding the research results of ancient China in magnetic phenomena and its impact on human civilisation and encouraging students to pay attention to the application of magnetic phenomena in life and production. iv) Understanding and being able to express the spatial distribution of the geomagnetic field clearly, and exercise their spatial imagination and spatial expression ability.	Demonstration of the magnetic phenomena with designed experiment. Students could apply magnetic knowledge to explain magnetic phenomena in life. Demonstration of Oersted's experiment, or group experiment if possible. Students could vividly see the magnetic lines of magnetic fields generated by various materials. Demonstrating the effect of a magnet on current, the effect of current and current. Analogising to Coulomb force and electric field, to form the concept of the magnetic field. Summary of the correlation between electric current and magnets. Introduce the magnetic field of the earth. gives a more detailed description of the magnetic declination and 'many celestial bodies in the universe have a magnetic field.'	Magnetism applications, e.g. magnet, magnet needle, speaker, electric motor, ammeter. Reading materials about research on magnetic phenomena in ancient China - Compass and Zheng He's Voyages. Reading material of earth's magnetic field and paleogeology. Rich questions progressively guide students to pay attention to the application of magnetic phenomena in life from the three levels of principle, application and classification.

(summarised from curriculum standard, teacher's teaching book and textbook (MoE, 2017b; Peng, 2009; Zhang, 2007))

This topic is the first section of the chapter on magnetism in the textbook, and teacher Jack wants to use the context to establish the basic rules that exist in the knowledge of magnetism and lay a foundation for electromagnetics (Table 4.8). The lesson focused on reviewing and improving the understanding of basic knowledge about magnetic field and experiencing magnetic phenomena. A video at the start of the lesson sets a question in students' minds, why a 'stone' attracts the pin, but a 'magnet' does not. Jack reveals half of the question, that the stone is a lodestone that has magnetism. Activities are planned to help students experience the distribution of the magnetic field around magnets and current. Then, students carry out experiments to experience the distribution and explore the direction of the magnetic field. At the end of the lesson, Jack summarises and introduces the Earth's magnetic field and the contributions of ancient Chinese to magnetic phenomena, which make the whole lesson from the explanation of knowledge to the contribution of knowledge to humanity, encourage students to learn science and try to make their contribution to science.

The teaching schedule about this topic in Jack's teaching plan is shown in Table 4.8. Compared with the officially recommended scheme (Table 4.7), the learning objectives feature the same concepts that as in the textbook. In terms of learning outcomes, the official recommendation is to give the corresponding learning objective to follow the sequence of concepts as these appear in the textbook. Jack takes magnetic field as the mainline concept, interspersed with additional basic concepts. The learning outcomes in Jack's plan are around magnetic field. In terms of teaching activities, Jack has arranged student group experiments based on teacher demonstration experiments according to official recommendations so students could better understand the distribution of magnetic fields. The teaching materials in Jack's plan are not limited to conventional reading materials, from the introduction video used to the demonstration experiment, and Jack carefully designs group experiments. The model designed to show the spatial distribution of the magnetic field around the bar magnet is delicate. It comprises results of the students' group experiments. Jack uses an iron-filing suspension to demonstrate the spatial distribution of the magnetic field around the bar magnets. This shows the spatial distribution clearly and can be used as a substitute demonstration experiment if the outcomes of the student group experiments are not obvious.

Table 4.8 Teaching schedule about Topic M, magnetic phenomena and magnetic field, in Jack's teaching plan

Prior knowledge: Basic electromagnetism			**Time taken:** 1 lesson
Learning objective	**Learning outcome**	**The overall sequence of lessons**	**Resources**
•Magnetism: the ability to attract metallic objects. •Magnetic pole: the region of a magnet where the external magnetic field is strongest. •Magnetic field: an invisible but objective substance that would give force to the magnetic or electric materials placed in it. •Magnetic lines never cross; the density of field lines indicates the strength of the field; could indicate the direction of the field; they always make closed loops. • Magnetic effect of current: Oersted's experiment; Ampère's rule. •Earth's magnetic field.	i) Knowing magnetic phenomena by giving examples; ii) Understanding the magnetic phenomena and the magnetic effect of current through experiments; iii) Understanding magnetic fields;	Episode 1 Setting a scene to arouse students' interest (display a cartoon and group experiment) (2 mins); Episode 2 Main task - experiencing the magnetic field around lodestone and bar magnet (demonstration experiment) (15 mins); Episode 3 Main task - exploring the magnetic effect of current and Ampère's rule (demonstration experiment) (20 mins); Episode 4 Summary task - reviewing the knowledge learnt in this class and introducing the properties of the magnetic field (4 mins); Episode 5 the magnetic phenomena in life (2 mins).	Video material of setting a scene to arouse students' interest. Group experiment materials of experiencing and exploring the magnetic phenomena and magnetic field. Demonstration experiment materials of the distribution of the magnetic field. Reading materials of earth's magnetic field. Blackboard writing and slides to guide students learning and summarising knowledge.

Five teachers' teaching designs are collected for Topic M. After analysing Jack's instructional design, Table 4.9 summarises the scheme of work of the other four teachers. The instructional designs are a brief introduction to teaching content and procedures. The analysis of the language would be meaningless. Therefore, this section and the following two topics compare and analyse similarities and differences among teaching plans from the aspects of knowledge structure and requirements, scientific methods and reasoning and teaching sequences.

The teaching objectives of these five teachers are set according to curriculum standard (Table 4.7). There would be slight discrepancies in the teaching outcomes; the requirements for the same knowledge point are consistent. The five teachers regarded the magnetic field (magnetic field line) and the relationship between electricity and magnetism as the focus for teaching. They design more teaching activities for these two contents than official suggested (Table 4.7). Jack, Lily and Sophia derive the existence of magnetic field from the magnetic phenomena and applications and then study how electricity and magnetism interact through the magnetic field. Oliver directly develops the concept of magnetic field based on the content of secondary school learning and then studies similarities and differences and interactions of electricity and magnetism. Leo uses the interaction of electricity and magnet as the opening of this lesson first then raises the question ‘how do they interact?' leading to the concept of magnetic field. The five teachers end their lessons with the application of magnetism and geomagnetic field.

Leo’s knowledge structure is more complete than that of other teachers, showing basic concepts and their interconnections to applications and cutting-edge knowledge. Oliver's plan involves the fewest concepts among the five; he allocates part of the time to the corresponding exercises (Table 4.9), which are not done by other teachers. The knowledge structure of Jack, Lily and Sophia is similar; Lily does not add the content of humanities education mentioned in the curriculum standard (Table 4.7).

Table 4.9 Four teachers' teaching plans about Topic M, magnetic phenomena and magnetic field

Prior knowledge: Basic electromagnetism		**Learning objectives**: See the suggested scheme	**Time taken**: 1 lesson
Teachers	**Learning outcome**	**The overall sequence of lessons**	**Resources**
Lily	i) Knowing magnetic phenomena by giving examples; ii) Understanding the definition and properties of magnetic fields and magnetic line; iii) Understanding the Ampère's rule; iv) Knowing the geomagnetic field.	Episode 1 Setting a scene to arouse students' interest (homemade teaching material) and discussing the magnetic phenomena in life (2 mins); Episode 2 Introducing Oersted's experiment and the information about the magnetic field (2 mins); Episode 3 Main task - exploring the properties of magnetic field line around magnets (10 mins); Episode 4 Main task - exploring the relationship between the current and magnetic field (15 mins); Episode 5 Summary task - reviewing the knowledge learnt in this class (5 mins); Episode 6 Introducing the Earth's magnetic field (5 mins);	Homemade material of setting a scene to arouse students' interest. Group experiment and Image materials of experiencing and exploring the magnetic field line and Ampère's rule. Blackboard writing and slides to guide students learning and summarising knowledge.
Sophia	i) Knowing magnetic phenomena; ii) Understanding the definition and properties of magnetic fields; iii) Understanding the relationships among current-carrying wires and magnets; iv) Knowing the ancient Chinese understanding of magnetism and the application of magnetism.	Episode 1 Demonstration of Gauss rifle as the introduction of the lesson and reviewing the knowledge learnt in secondary school (8 mins); Episode 2 Main task – doing group experiment of the Oersted's experiment (15 mins); Episode 3 Main task - demonstrating the force between two parallel current-carrying wire (2 mins); Episode 4 Main task - introducing the properties of the magnetic field (10 mins); Episode 5 Main task - introducing the applications of the magnetic field (5 mins); Episode 6 Summary task - introducing the ancient Chinese understanding of magnetism and reviewing the knowledge learnt in this class (5 mins);	Group experiment materials of experiencing and exploring Oersted's experiment. Demonstration experiment and image materials of the distribution and applications of the magnetic field. Blackboard writing, slides and poem to guide students learning and summarising knowledge.

Leo	i) Understanding the interaction between electricity and magnetism; ii) Understanding the definition and properties of magnetic fields; iii) Knowing the geomagnetic field.	Episode 1 making magic as an introduction and review the knowledge learnt in secondary school (5 mins); Episode 2 Main task - exploring the interaction between electric and magnetism and the application of the interaction (15 mins); Episode 3 Main task - exploring the interaction among current-carrying wires (5 mins); Episode 4 Main task – introducing the definition and properties of the magnetic field (5 mins); Episode 5 Main task - introducing Sinan (compass) the Earth's magnetic field (8 mins); Episode 6 Summary task - reviewing the knowledge learnt in this class and arranging the homework (2 mins);	Group experiment and demonstration experiment materials of experiencing and exploring the interaction among electricity and magnetism. Blackboard writing and slides to guide students learning and summarising knowledge. Video material of the Earth's magnetic field
Oliver	i) Understanding the definition and properties of magnetic fields; ii) Understanding the similarities and differences between the electric field line and magnetic field line; iii) Knowing the geomagnetic field.	Episode 1 to reviewing the knowledge learnt in secondary school (5 mins); Episode 2 Main task – introducing the definition and properties of the magnetic field (10 mins); Episode 3 Main task - introducing the definition and properties of magnetic field line (5 mins); Episode 4 Main task - introducing the direction determination method of three kinds of the magnetic field (15 mins); Episode 5 Summary task - to compare the electric field line and magnetic field line (5 mins); Episode 6 to introduce the Earth's magnetic field (5 mins);	Image materials of setting a scene to arouse students' interest and demonstrating the magnetic field and magnetic field line. Blackboard writing and slides to guide students learning and summarising knowledge. Consolidation exercise

In teaching, the explicit use of scientific methods helps students understand knowledge. In Jack, Lily, Sophia and Leo's teaching, the process of scientists' discovering knowledge related to magnetic phenomena and magnetic fields were reproduced through small group or demonstration experiments. This deepens students' understanding of related concepts. Oliver's plan does not involve experiments but instead makes the logical relationship between concepts explicit through analysis and questioning. These methods intend to make the scientific method explicit; the effect depends on the performance of the teacher and students in the classroom.

The teaching sequences of the five teachers' teaching plans are based on students' cognition sequences. The process is introduction-experiment-concept-experiment-concept-summary-application. Divergences occur in materials used by the teachers as an introduction and in the teaching order of the concepts. The design of Lily's introduction follows the introduction recommended by the curriculum standard and the teacher book, using the experiment and the magnetic phenomena. Jack uses video and group experiments as an introduction. Oliver starts with the knowledge that they learned in secondary school. The introduction of Leo and Sophia's plan combines the above two. In addition to using experiments, a review of secondary school knowledge is added to Leo and Sophia's plan.

After entering the main task, Lily and Sophia first introduce Oersted's experiment, then show the magnetic field distribution around the current, and introduce the magnetic field's nature. Lily highlights the experimental operation specifications in the instructional design, indicating that Lily pays great attention to the experimental operation. Sophia focuses on introducing applications of magnetic fields throughout the lesson. Some experiments Sophia involves in her lesson exist in the following topic in the textbook (CUT). In contrast, Jack uses experiments to demonstrate distribution of magnetic field, explaining that electricity and magnetism are related. Oliver introduces the magnetic field first; he does not use experiments. He uses language to explain logically and pictures and blackboard to introduce the nature of the magnetic field and magnetic field lines. Finally, he summarises the relationship between electricity and magnetism via the corresponding exercises to consolidate knowledge understanding (Table 4.9). Leo demonstrates the interaction of electricity and magnetism and points out that the medium of this interaction is the magnetic field. The five teachers end with the application of the magnetic and geomagnetic fields, allowing students to apply the knowledge to explain the actual phenomenon. Sophia and Leo point out the understanding of magnetism in ancient China and the study of magnetism in frontier science for humanistic education.

In summary, the five teachers follow the knowledge arrangement and requirements of the curriculum standards and the teacher book in teaching design. They make their adjustments in the presentation form, including knowledge structure, presentation and the materials used to facilitate explanation and understanding. Oliver's teaching is the most special one. The whole lesson does not include any experiments. Instead, only language explanations, images and exercises are involved. This challenges that the richer the teaching materials used in a lesson, the more effective it will be. When the other four teachers choose examples and experiments to illustrate, Oliver believes that experiments will waste class time (M5-I). Provided students can keep up with the teacher's explanation, they have a deeper understanding of physics concepts quickly (section 4.2). Oliver regards the physics curriculum as an integrated curriculum. If the teacher has the maximum authority or supervision power, knowledge would be easy to transfer. This rigid and hierarchical characteristic depends on the popular culture of society. Without assistance from group experiments and demonstration experiments, teaching outcomes depend on the specific teaching process and Oliver’s understanding of the teaching and the students of this lesson.

4.4.2 *Topic F: force on the current-carrying wire in a magnetic field*

The direction and magnitude of the Ampère force are the focus of this topic. It is difficult to understand the spatial relationship between Ampère force's direction, current, and magnetic flux density. Ampère force (F) must be perpendicular to current (I) and magnetic flux density (B). I and B can be at any angle; when I is perpendicular to B, the Ampère force is the largest. Students often confuse this. For example, when solving problems, they mistakenly think that the Ampère force, current, and magnetic flux density must be perpendicular to each other. Besides, spatial imagination is essential for the study in this section. To enable students to understand the three-dimensional view and be familiar with the side view, top view and cross-sectional view of various angles, teachers should add a certain amount of training for consolidating.

After introducing the Ampère force's definition, a demonstration experiment guides students to observe, record, and analyse the phenomenon seriously. The process of experiment recording and analysis cultivates students' spatial thinking ability (Peng, 2009). Some students have difficulties in judging *the direction of the Ampère force* when the magnetic field is not perpendicular to the current. Therefore, the demonstration may change the magnetic field's direction so that the angle between it and the current direction is not equal to 0° or 90°. The teacher guides students to observe and record the Ampère force's direction in this situation to verify the left-hand rule. It could be helpful to avoid students thinking that the Ampère force, current, and magnetic field line must be perpendicular to each other. The left-hand rule involves three physics quantity directions. The three-dimensional graphic is intuitive and realistic; it is a difficulty in teaching (Peng, 2009). Thus, the teaching of three-dimensional graphics should be emphasised in teaching and let the students practice repeatedly. The three-dimensional graphic is not as clear and accurate as the two-dimensional graphics in terms of direction, angle, and force (Peng, 2009). Therefore, it is necessary to train students on using side, top, and cross-sectional views to master the left-hand rule.

Besides, teachers should guide students to distinguish between the Ampère's rule and the left-hand rule, using these to explain the demonstration experiment of ‘interaction between parallel current-carrying straight wires’. Students should understand that the Ampère force received by the current-carrying wire on the left is applied by the magnetic field generated by the current-carrying wire on the right, and vice versa.

Studying *the magnitude of Ampère force* could follow inductive reasoning, shown in the following:

$$B = \frac{F}{IL} \quad \rightarrow \quad \begin{cases} I \perp B, F = BIL \\ I \parallel B, F = 0 \end{cases} \quad \rightarrow \quad F = BIL\sin\theta$$

The derivation could refer to the superposition of the electric field and the synthesis of electrostatic force.

Peng (2009) pointed out that teachers should tell students to combine the three-dimensional diagram in the textbook with the scientific methods used in the derivation. To avoid abstract mathematical derivation away from the specific issues, the magnitude and direction of the Ampère force are discussed in specific context. Making the scientific methods explicit is a benefit for students understanding the derivation process and the physics concept.

The teacher book suggested that analogising Ampère force with Coulomb force (Peng, 2009). If students are not proficient in the Coulomb force, this will affect learning of the new concept (Taber, 2013). Besides, teachers can point out that the 'direction of current' is the 'direction of wire'. The current is scalar. The "direction of current" is not the same as the vector orientation in space.

The students have utilized the ammeter in their previous physics experiment class, thereby comprehending its purpose and key parameters. This prior knowledge has laid a solid foundation for delving into the structural principles of the *magneto-electric ammeter*. The instructional approach should commence with direct observation of the physical device, followed by a concise qualitative explanation that integrates relevant illustrations from the textbook (CUT). The teacher's role is to guide students towards identifying:

- How does the rotation of the coil occur? Why doesn't the coil keep spinning?
- Why does the pointer deflection angle indicate the strength of the measured current?
- How to determine the current direction on the circuit according to the direction of the pointer deflection angle?
- To what should you pay special attention to when using it?

It is possible to propose ‘how to ensure that the current scale of the magneto-electric ammeter is uniform’ for the capable student to think and study further.

Table 4.10 summarises the suggested teaching schedule about the force on the current-carrying wire in a magnetic field based on the curriculum standard, teacher's teaching book and textbook. The official teaching materials are relatively abundant in the teaching suggestions given in this lesson. The teaching suggestions provide teachers with suggestions on related exercises and guidance questions. The course materials are general, and teachers need to make specific adjustments for their classrooms.

Table 4.10 Suggested teaching schedule about Topic F, force on the current-carrying wire in the magnetic field

Prior knowledge: Basic electromagnetism and magnetic flux density		**Time taken**: 1 lesson	
Learning objective	**Learning outcome**	**Learning activity with the opportunity to develop skills**	**Resources**
•Ampère force: a current-carrying wire placed at an external magnetic field experiences a force due to the field, the force is called Ampère force, $F = BIlsin\,\theta$ • Left-hand rule: Extend the left hand so that the thumb is perpendicular to the other four fingers and all are in the same plane as the palm; let the magnetic induction line enter into the palm and point the four fingers in the direction of the current, then the direction of the thumb is the direction of the Ampère force that the current conducting wire current-carrying wire experienced in the magnetic field.	i) Observing the experiment to find out the factors that the direction of Ampère force depends on, recording the experimental phenomena and drawing relevant conclusions. Knowing that the direction of the Ampère force is perpendicular to the direction of current and magnetic flux density, applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field. ii) Deriving the equation of Ampère force in the uniform magnetic field and calculating the magnitude of Ampère force in the uniform magnetic field. iii) Knowing the basic structure of the magneto-electric ammeter and the basic principle of using it to measure the magnitude and direction of the current.	Demonstration of the factors that the direction of Ampère force depends on. Introducing the left-hand rule. Giving worked examples. Deriving the equation of Ampère force in the uniform magnetic field and measure the magnitude of Ampère force in the uniform magnetic field (equivalent substitution and induction reasoning). Giving worked examples. Demonstrating the magneto-electric ammeter. Demonstrating the experiment in 'Have a try'.	Demonstration experiment of the interaction between two parallel current-carrying wire. Demonstration experiment of the factors that the direction of Ampère force depends on. Reading materials about measuring the magnitude of Ampère force in the uniform magnetic field. Worked examples. Rich questions progressively guide students in understanding the principle of the magneto-electric ammeter.

(summarised from curriculum standard, teacher's teaching book and textbook (MoE, 2017b; Peng, 2009; Zhang, 2007))

These five teachers' teaching objectives are set according to the curriculum standards, with slight discrepancies in teaching outcomes. The five teachers regard research on the magnitude and direction of Ampère force as the focus of teaching and the content that students need to understand and apply. Thus, additional teaching activities and exercises are designed for the Ampère force based on the teaching material. The five teachers exhibit differences in their arrangement of teaching. Freddie introduces the content of magnetic flux density in the previous lesson to his students. The definition and equation of Ampère force become the prior knowledge of Freddie's lesson, as recommended in the teacher's book. The focus of Freddie's lesson is on determining the direction of Ampère force and the derivation process of the equation. There is time to practice applying the left-hand rule and deriving the expression of Ampère force at any angle between B and I. The left-hand rule application chooses the magneto-electric ammeter.

Charlie, Ava, George and Oscar put the content of magnetic flux density in the next lesson. The equation and magnitude of Ampère force as new knowledge are designed to explore influencing factors through corresponding experiments and questions. To start, Charlie measures the magnitude of Ampère force; defines Ampère force; and then studied the direction of Ampère force. This is similar to Freddie's design, in which the Ampère force magnitude is prior knowledge to the Ampère force direction. Losing the Ampère force equation and B as pre-knowledge, the time allocated for the equation derivation for the non-extreme value of the Ampère force and the left-hand rule application to determine the direction of the Ampère force are compressed. In Charlie, Ava, George and Oscar's classes, the general equation of Ampère force (at any angle between B and I) is not involved, but referred to as an after-class ‘thinking’ assignment, to be explained in the next class.

All five teachers use experiments to demonstrate the physics process. Freddie requires students to observe the experiment to get the factors of Ampère force's direction and the relationship between the factors. When Charlie, Ava, George, and Oscar plan to guide students to guess the factors of the magnitude and direction of Ampère force, they emphasise using experiments to simulate and verify the physics issue. Before and during the demonstration and group experiments detailed analysis of the experimental structure and precautions are given, and the students divided in detail in the teaching plan. The teacher has strong control over the classroom, so students could operate independently, but according to the teacher assigned tasks. Freddie's classroom is mainly lecturing, with students' ideas following. Teachers' control of the classroom is powerful in Freddie's class. Control depends on how teachers use language to organise the lesson. Charlie, George and Oscar emphasise in the experimental activities that the method used is the control variable method. In this topic, there are three variables, B, I and L.

Therefore, the control variable method is used to quantitatively study the relationship between these three variables and Ampère force. Oscar proposes using the inductive method in the equation derivation process, from unique to general, that is, expression of the Ampère force when the angle the current makes with the magnetic field is between 90° and 0°, the two particular positions to any positions. Freddie’s lesson deduces the general expression of Ampère force, yet he does not point out the physics method explicitly.

The objectives of this topic are clear. The direction and magnitude of the Ampère force and the left-hand rule for determining the direction of Ampère force are the main content. The basic teaching process of this lesson is to demonstrate the experiment - define Ampère force - confirm the influencing factors - explore the magnitude and direction of the Ampère force - introduce the left-hand rule and apply it - summarise the knowledge. The designs of the teaching sequences of the five teachers are similar. Freddie has already talked about the equation and magnetic flux density in his previous lesson, in the equation derivation process, Freddie focuses on the general equation of Ampère force: $F = BIlsin\,\theta$. Freddie uses exercises, questions and knowledge summaries as the final part of this lesson. Ava and George are the same as the teaching process suggested in the teacher's book. Ava and George use grouping experiments and demonstration experiments to study the magnitude of Ampère force and their relationship. After deducing the specific equation of Ampère force, Ava leaves the general equation as a thinking question for homework and then summarises the knowledge learned in this lesson. George does not mention general equation; he introduces experiments and simple electric motor as analytical materials to allow students to consolidate further what they learned. Charlie and Oscar explore the factors of Ampère force based on the introduction experiment. They then deduce the formula of Ampère force when I is perpendicular to B based on a demonstration experiment or group experiment. Then, they guide students to study the direction of Ampère force and introduce the left-hand rule. Charlie concludes by summarising the content of this lesson. Oscar introduces the interaction of parallel wires, the introduction experiment and a simple electric motor as the analysis materials to consolidate the students' application of the left-hand rule.

In summary, the five teachers follow the knowledge layout and requirements of the curriculum standard and teacher’s book in their teaching design. Charlie, Ava, George and Oscar adjust the book's teaching order, resulting in magnetic flux density and the equation of Ampère force becoming unlearned content instead of prior knowledge. These four teachers’ designs take the factors that affect the Ampère force as the inquiry content. This leads to time constraints and deletes teaching time for the derivation of general equation of Ampère force and application of the left-hand rule. Freddie's teaching design almost completely follows the recommendations of the teacher's book with the additional classroom exercises. He does not highlight physics reasoning in this lesson and spends more time on mathematical derivation and consolidation of students' memory of knowledge. The other four teachers include demonstration and group experiments and pay attention to the explicitness of physics methods and the emphasis on experimental norms. How teachers use language and present teaching materials are presented in the next chapter.

Table 4.11 The five teachers' teaching plans about Topic F, force on the current-carrying wire in the magnetic field

Prior knowledge: Basic electromagnetism	**Learning objectives**: See the learning outcome		**Time taken**: 1 lesson
Teachers	**Learning outcome**	**The overall sequence of lessons**	**Resources**
Charlie	i) Knowing the definition of Ampère force and deriving the equation of Ampère force; ii) Applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field;	Episode 1 reviewing the knowledge learnt in the previous lessons- the magnetic effect of current and verifying that the existence of Ampère force (group experiment) (3 mins); Episode 2 Main task - exploring the factors that the magnitude of Ampère force depends on and deriving the equation of Ampère force (demonstration experiment) (25 mins); Episode 3 Main task - determining the direction of the force on a current-carrying wire in a magnetic field - left-hand rule (demonstration experiment) (10 mins); Episode 4 Summary task - reviewing the knowledge learnt in this class (2 mins);	Group experiment and Image materials of experiencing the Ampère force. Demonstration experiment materials to explore the magnitude and direction of Ampère force. Blackboard writing and slides to guide students learning and summarising knowledge.
Ava	i) Knowing the definition of Ampère force; ii) Applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field; iii) Deriving the equation of Ampère force; iv) Knowing the application of Ampère force, Rail Gun.	Episode 1 introducing the lesson with a demonstration experiment (4 mins); Episode 2 Main task -introducing the definition of Ampère force, exploring the factors that the direction of Ampère force depends on and introducing the left-hand rule (group experiment) (10 mins); Episode 3 Main task - exploring the factors that the magnitude of Ampère force depends on (group experiment) (25 mins); Episode 4 Summary task - giving questions for students thinking and reviewing the knowledge learnt in this class (2 mins);	Homemade material of setting a scene to arouse students' interest. Group experiment materials for exploring the direction and magnitude of Ampère force. Video material for introducing the rail gun. Blackboard writing and slides to guide students learning and summarising knowledge.

George	i) Knowing the definition of Ampère force; ii) Applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field; iii) Deriving the equation of Ampère force; iv) Knowing the applications of Ampère force,	Episode 1 introducing the lesson with a demonstration experiment and giving the definition of Ampère force (2 mins); Episode 2 Main task - exploring the factors that the direction of Ampère force depends on (demonstration experiment) (8 mins); Episode 3 Main task - exploring the relationship among the direction of B, I, F (group experiment) and introducing the left-hand rule (12 mins); Episode 4 Main task - exploring the factors that the magnitude of Ampère force depends on (demonstration experiment) and deriving the equation of Ampère force (14 mins); Episode 5 Summary task - applying the knowledge to explain the principle of introduction experiment and electric motor (5 mins);	Group experiment and demonstration experiment materials of experiencing and exploring the direction and magnitude of Ampère force. Blackboard writing and slides to guide students learning and summarising knowledge. Demonstration experiment materials of applying the knowledge
Oscar	i) Knowing the definition of Ampère force; ii) Deriving the equation of Ampère force; iii) Applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field; iv) Applying the left-hand rule to explain the interaction between two parallel current-carrying wires, the introduction experiment and electric motor.	Episode 1 introducing the lesson with a homemade experiment and giving the definition of Ampère force (2 mins); Episode 2 Main task - exploring the factors that the magnitude of Ampère force depends on (demonstration experiment) (5 mins); Episode 3 Main task - deriving the equation of Ampère force (group experiment) (15 mins); Episode 4 Main task - exploring the factors that the direction of Ampère force depends on (demonstration experiment) (12 mins); Episode 5 Main task - introducing left-hand rule and applying it to explain the interaction between two parallel current-carrying wires, the introduction experiment and electric motor (8 mins);	Homemade material of setting a scene to arouse students' interest. Group experiment and demonstration experiment materials of experiencing and exploring the direction and magnitude of Ampère force. Blackboard writing and slides to guide students learning and summarising knowledge.

Freddie	i) Observing the experiment to find out the factors that the direction of Ampère force depends on. Knowing that the direction of the Ampère force is perpendicular to the direction of current and magnetic flux density, ii) Applying the left-hand rule to determine the direction of the force on a current-carrying wire in a magnetic field. iii) Deriving the equation of Ampère force in the uniform magnetic field and measure the magnitude of Ampère force in the uniform magnetic field. iv) Knowing the basic structure and principle of the magnetoelectric ammeter.	Episode 1 Giving the definition of Ampère's force (2 mins); Episode 2 Main task - exploring the factors that the direction of Ampère force depends on, introducing the left-hand rule and applying it to explain the interaction between two parallel current-carrying wire (20 mins); Episode 3 Main task - deriving the equation of Ampère force in the uniform magnetic field and measuring the magnitude of Ampère force in the uniform magnetic field (12 mins); Episode 4 Main task - introducing the basic structure and principle of the magnetoelectric ammeter (8 mins); Episode 5 Exercises- applying the knowledge learnt in exercises (5 mins); Episode 6 Summary task - summarising the content learnt in this lesson (2 mins);	Demonstration experiment materials of experiencing and exploring the factors that the direction of Ampère force depends on. Image materials of demonstration. Blackboard writing and slides to guide students learning and summarising knowledge. Consolidation exercise

4.4.3 *Topic E: electric field strength*

The textbook (CUT) starts with the force on charges in the electric field, and introduces the concept of electric field strength. This physics quantity describes the strength of an electric field. This topic comprises electric field, electric field strength, the superposition of a point charge electric field strength, electric field lines, and uniform electric field (Peng, Q., 2013).

In the textbook, electric field strength is defined via the ratio definition. The ratio does not relate with the charge amount of the test charge and reflects a certain property of space, the electric field strength. In a sense, the introduction of the electric field strength defines the electric field. Materiality of electric field should be mentioned, but not overemphasised. Because students lack perceptual knowledge about the existence of electric field, this takes time to learn and gradually accept (Peng, 2009). This lesson requires students to understand that an electric field is a form of objective existence and exerts a force on charges in it, which is a way to examine its existence (MoE, 2017b).

Understanding of electric field strength should be evident in the following points (Peng, 2009): it does not depend on the existence and properties of the test charge placed in it. Students should know the definition of electric field strength, understand its vector and superposition, and describe electric field with electric field lines.

The textbook (CUT) discusses whether there is an action-at-a-distance in physics history, comparing electrostatic force with gravitation, and directly puts forward Faraday's view that charges around them generate an electric field. The field is an essential concept in physics. It is invisible and untouchable, so is abstract. Through reading materials, students perceive scientists' description of the electric field for humanistic education. Teachers may compare the electrostatic force with the magnetic force between magnets. Considering students learned the concept of magnetic field in lower-secondary school, the analogy makes use of their learned knowledge, so establishing the concept of electric field would be natural. This topic studies electric field generated by static electric charges, that is, the electrostatic field. The interaction between static charges occurs accomplished through the interaction of electrostatic fields.

The teaching of *electric field strength* is completed in three steps. Firstly, teachers guide students to understand the magnitude and direction of electric field strength. The most noticeable feature of an electric field is that it exerts an electrostatic force on the charges placed in it. In the teaching design, teachers add a demonstration experiment in the previous lesson (Coulomb's law). This should guide students to understand the field source charge, text charge and the factors on the Coulomb force ($F = k\frac{q_1 q_2}{r^2}$).

The second step is looking for a physics quantity that could describe the properties of the electric field. The electrostatic force (electric field force) experienced by the test charge cannot describe the strength of the electric field. According to Coulomb's law, the magnitude of the electric field force (F) is related to the electric field (E) and the amount of charge (q) of the test charge (E = Fq). The physics quantity (E) used to describe the properties of the electric field does not relate to the test charge. The experiment shows, this physics quantity should related to the distance with the charged metal ball O. The deductive process of the defining equation of electric field strength ($E = \frac{F}{q}$) in textbook should not be ignored; teachers cultivate students' logical thinking ability through this process. The teaching should show the physics meaning of the ratio, guiding students to experience this definition method. If students are exposed to the physics quantities defined by ratio, such as density and speed, they understand this proportional equation mathematically. Physics teachers must guide students to understand the physics meaning of this equation ($E = \frac{F}{q}$).

Finally, the direction of electric field strength should be described. From the demonstration experiment, lead the students to discuss: ‘ If put you the same probe test charge at different positions in the electric field, is the direction of the electrostatic force on the test charge the same?’ After discussion, students understand the electric field strength describes both the magnitude and the direction of the electric field; it is a vector. Correcting the misconception helps students understand the regulations of the direction of the electric field strength, namely that the direction of the electrostatic force on a test charge of a certain point in the electric field does not always align with the direction of the electric field strength at the point. The force on a positive test charge is in the same direction as the electric field strength, while the force on a negative test charge is in the opposite direction.

The explanation of *superposition of the electric field strength* depends on the demonstration experiment. Combining the definition equation of electric field strength with Coulomb's law, the electric field strength formula of the point charge is obtained: $E = \frac{F}{q} = k\frac{Q}{r^2}$.

Through the study of *electric field lines*, students realise how virtual graphs describe abstract physics concepts, making physics concepts concrete and figurative. This fully embodies an essential method of thinking in scientific research. Clarify that electric field lines express the direction and magnitude of the electric field. Electric field lines start from a positive charge or infinity and end at infinity or a negative charge. The non-intersection of the electric field lines in the same electric field indicates the uniqueness of the electric field strength in the electric field. There are no electric field lines in the electric field; the electric field lines are a useful tool to describe the electric field vividly. Through the study of electric field lines, students understand the electric field line distribution diagrams of specific electric fields, and apply the electric field lines to describe them, students could realise that describing abstract physics concepts with virtual lines is a scientific reasoning method.

The teaching of *uniform electric field* involves definition, characteristics of the electric field lines in it, and what kind of electric field in real life is regarded as uniform electric field.

Table 4.12 Suggested teaching schedule about Topic E, electric field strength

Prior knowledge: Basic electromagnetism and Coulomb's law			**Taken time**: 1 lesson
Learning objective	**Learning outcome**	**Learning activity with the opportunity to develop skills**	**Resources**
•Electric field •Electric field strength •Superposition of electric field strength • Electric field line •Uniform electric field.	i) Knowing that the interaction between charges is achieved through electric fields. Knowing that field and object are two different forms of objective existence. ii) Experiencing the method of defining physics quantities with ratio, and understanding the definition equation, unit, and direction of electric field strength. iii) Deriving the equation of the electric field strength around a point charge, and performing related calculations. Knowing the superposition principle of electric field strength and applying this principle to simple calculations iv) Knowing the definition and characteristics of electric field lines and applying electric field lines to describe the magnitude and direction of electric field strength.	Reading the research on the action at a distance to introduce the electric field. Demonstrating the experiment in the last lesson to explore the properties of electric field strength. Deriving the equation of the electric field strength around a point charge and pointing out the method of defining physics quantities with ratio. Deriving the superposition principle of electric field strength. Introducing the uniform electric field.	Reading materials about research on the action at a distance and Faraday's concept of field. Demonstration experiment of experiencing and exploring the direction and magnitude of electric field strength and electric field lines. Reading materials about the method of defining physics quantities with ratio. Mathematical deduction and image materials of superposition of electric field strength.

(summarised from curriculum standard, teacher's teaching book and textbook (MoE, 2017b; Peng, 2009; Zhang, 2007))

There is much content in this topic, mentioned when analysing the textbook (section 4.3.2). CUT arranges electric field, electric field strength, point charge's electric field strength and superposition, electric field lines and uniform electric field in one class. Six of the seven teachers exhibit different knowledge arrangements for this class. Only Emily's knowledge structure was the same as the textbook (CUT). Emily included all textbook content in her teaching design, and her presentation process followed the suggestions in the teacher book. Emily added corresponding exercises and application examples to facilitate learning. The teaching designs of Ivy, Emily, Ella, Daisy and Hannah included electric field, electric field intensity and electric field strength of point charge and its superposition. They put the content of electric field lines and uniform electric field into the next lesson. Luna dealt with the concept of the electric field, electric field strength and electric field strength of point charge in this lesson. Emily contained all knowledge, but the time allocated to each part seemed insufficient. The other six teachers modified the knowledge range to give students practice and thinking time, consolidating learning.

The seven teachers' designs presented the knowledge in the same order, albeit with slightly different structures. Ivy, Emily and Ella regarded electric field, electric field strength, point-charge electric field strength, and superposition as four parts and explained them separately. These parts are interrelated, and teachers should pay attention to connection between concepts and echo back and forth when teaching to help students build knowledge networks. Emily and Daisy linked electric field strength with the electric field strength of a point charge, and explained this according to the definition equation ($E = \frac{F}{q}$) and determination equation ($E = k\frac{Q}{r^2}$) of the point charge's electric field strength. This classification method may confuse students with the conditions of determination equation. The determination equation is unique to the electric field strength of a point charge, while the previous definition equation is applicable to all electric fields. Luna mentioned the equation of the electric field strength of a point charge as a determination equation and compared it with the general definition equation. Luna proposed the directions of electric field strength separately. Respectively lecturing on the magnitude and direction of the electric field strength highlights the vector nature of the electric field strength. This may separate the students' concept of the magnitude and direction of electric field strength. Hannah's plan followed the knowledge structure in the textbook. This put electric field strength of a point charge and their superposition in a unit to explain and practice, which separated the unique situation of the electric field strength of a point charge from the general one. Teachers' strategies to deal with the defects in the design of knowledge structure in their teaching require the analysis of the teacher's classroom records (section 5.3).

Table 4.13 The seven teachers' teaching plan about Topic E, electric field strength

Prior knowledge: Basic electromagnetism and Coulomb's law		**Learning objectives**: See the learning outcome	**Time taken**: 1 lesson
Teachers	**Learning outcome**	**The overall sequence of lessons**	**Resources**
Ivy	i) Knowing that the interaction between charges occurs through an electric field; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge; iv) Knowing the principle of electric field strength superposition,	Episode 1 A charged metal ball would experience a force from another charged metal ball (demonstration experiment) and review the content about Coulomb's law, then arising two questions (2 mins); Episode 2 Giving the learning outcomes (2 mins); Episode 3 Main task - Introducing the concept of electric field and the electric field strength (26 mins); Episode 4 Main task - Deriving the equation of electric field strength of a point charge and introducing the principle of electric field strength superposition (10 mins); Episode 5 Summary task - reviewing the basic knowledge and scientific methods learnt in the lesson (2 mins);	Demonstration experiment materials of arising two questions for preparing the introduction of electric field and electric field strength. Blackboard writing and slides to guide students learning and summarising knowledge. Rich exercise and worked examples of applying the knowledge.
Emily	i) Knowing that the interaction between charges is achieved through electric fields; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge; iv) Knowing the principle of electric field strength superposition,	Episode 1 Introduction activity, shaking hand and playing a video (5 mins); Episode 2 Main task - Introducing the concept of the electric field (demonstration experiment) (5 mins); Episode 3 Main task - Exploring the factors on electric field force (demonstration experiment) and introducing the electric field strength (20 mins); Episode 4 Main task - Deriving the equation of electric field strength of a point charge and introducing the principle of electric field strength superposition (10 mins); Episode 5 Summary task - Reviewing the basic knowledge learnt in the lesson (2 mins);	Video material and activities of setting a scene to arouse students' interest. Demonstration experiment materials of experiencing and exploring the electric field and electric field strength. Blackboard writing and slides to guide students learning and summarising knowledge. Worked examples of applying the knowledge.

Emily	i) Knowing the definition and property of the electric field; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge and knowing the field lines; iv) Knowing the principle of electric field strength superposition and uniform electric field.	Episode 1 Reviewing the Coulomb's law and contact and non-contact force, and introducing the related physics history (demonstration experiment) (5 mins); Episode 2 Main task - Introducing the electric field and the electric field strength (mathematical deduction and worked examples) (20 mins); Episode 3 Main task - Deriving the equation of electric field strength of a point charge and introducing the field lines (mathematical deduction and worked examples) (10 mins); Episode 4 Main task - Introducing the principle of electric field strength superposition and uniform electric field (mathematical deduction and worked examples) (3 mins); Episode 5 Summary task - Introducing the application of electric field strength and reviewing the knowledge (4 mins);	Demonstration experiment materials of experiencing and exploring the electric field and electric field strength. Blackboard writing and slides to guide students learning and summarising knowledge. Worked examples of applying the knowledge.
Ella	i) Knowing the definition and property of the electric field; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge; iv) Knowing the principle of electric field strength superposition.	Episode 1 Experiencing the existence of the electric field, reviewing the Coulomb's law and introducing the physics history (demonstration experiment) (5 mins); Episode 2 Main task - Introducing the electric field (video) (10 mins); Episode 3 Main task - Introducing the electric field strength (worked examples) (15 mins); Episode 4 Main task - Deriving the equation of electric field strength of a point charge and introducing the principle of electric field strength superposition (10 mins); Episode 5 Summary task - Reviewing the knowledge(2 mins);	Demonstration experiment and video materials of experiencing and exploring the electric field and electric field strength. Blackboard writing and slides to guide students learning and summarising knowledge. Rich exercise and worked examples of applying the knowledge.

Daisy	i) Knowing the definition and property of the electric field; ii) Understanding the concept, definition and vector of electric field strength, and deriving the equation of electric field strength of a point charge; iii) Knowing the principle of electric field strength superposition.	Episode 1 'What is spring?' and reviewing the demonstration experiment (picture) (4 mins); Episode 2 Main task - Introducing the electric field (6 mins); Episode 3 Main task - Introducing the electric field strength, deriving the equation of electric field strength of a point charge and introducing the principle of electric field strength superposition (worked examples and exercises) (30 mins); Episode 4 Summary task - Reviewing the knowledge points (2 mins);	Image material of experiencing and reviewing the electric field. Blackboard writing and slides to guide students learning and summarising knowledge. Rich exercise and worked examples of applying the knowledge.
Hannah	i) Knowing the definition and property of the electric field; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge and knowing the principle of electric field strength superposition.	Episode 1 Introduction activity, reviewing the Coulomb's law (demonstration experiment) and introducing the physics history (5 mins); Episode 2 Main task - Introducing the electric field (5 mins); Episode 3 Main task - Introducing the electric field strength (image and demonstration experiment) (15 mins); Episode 4 Main task - Deriving the equation of electric field strength of a point charge and knowing the principle of electric field strength superposition (demonstration experiment and worked examples) (15 mins); Episode 5 Summary task – Arranging homework and reviewing the knowledge (2 mins);	Image and demonstration material of experiencing and exploring the electric field and electric field strength. Blackboard writing and slides to guide students learning and summarising knowledge. Rich exercise and worked examples of applying the knowledge.

Luna	i) Knowing the definition and property of the electric field; ii) Understanding the concept, definition and vector of electric field strength; iii) Deriving the equation of electric field strength of a point charge.	Episode 1 Introduction activity and demonstrating the force on the charged ball near another charged ball (2 mins); Episode 2 Main task – Reviewing other non-contact force, introducing electric field and its physics history (searching information and demonstration experiment) (12 mins); Episode 3 Main task – Introducing the electric field strength (worked examples, group discussion and demonstration experiment) (20 mins); Episode 4 Main task - Deriving the equation of electric field strength of a point charge (demonstration activity) (5 mins); Episode 5 Summary task - Arranging homework and reviewing the knowledge (2 mins);	Demonstration material of experiencing and exploring the electric field and electric field strength. Reading materials about research on the action at a distance and Faraday's concept of field. Blackboard writing and slides to guide students learning and summarising knowledge. Worked examples of applying the knowledge.

The textbook of this lesson contains an explicit method, the ratio definition method of physics quantity. The seven teachers mentioned this method in their instructional design and emphasise the physics meaning of this definition method, that is, E, at a point in the field is defined as the force per unit charge on a positive test charge placed at that point. E is not determined by F and q. The electric field strength is determined by the field source charge and is not related to the property of the test charge. The test charge involved is an ideal model, which teachers did not directly mention in their teaching design. The knowledge summary part of Ivy and Daisy involved concepts and scientific methods, the ratio definition method and ideal model. The other five teachers only summarised the concepts. Whether the teacher reveals the physics methods in the lesson explicitly through language in teaching requires further analysis of their classroom records (section 5.3).

The teaching sequences of the seven teachers follow the recommendations of the teacher book, except that exercises and presentation materials added are various. This lesson requires students to have high comprehension skills, so accordingly the seven teachers designed a wealth of questions, examples, and demonstration materials. Ivy, Emily, Ella, Hannah and Luna adopted the demonstration experiment of Coulomb's law to let students experience the existence and strength of the electric field. Emily and Daisy showed a schematic diagram of the demonstration experiment to help students recall the demonstration experiment from the previous class. In addition to Ivy, the other six teachers added the history of physics to help students understand. Among them, Emily presented the physics history content in the video format of a vivid debate. When Hannah and Luna explained the direction of electric field strength, they adopted the activity demonstration, allowing students to participate and experience the direction change of electric field strength.

In summary, in terms of the breadth of knowledge coverage, Emily stands out as the sole teacher who adhered strictly to the teaching suggestions in her design, while other teachers made certain modifications. Hannah's plan closely aligns with the structure outlined in the textbook. The other teachers provided explanations and imparted via various combinations of knowledge. Regarding the presentation of scientific methods and teaching sequence, seven teachers faithfully followed the official teaching suggestions.

4.4.4 *Summary*

Discrepancies among topics: The comparison of the overall trend of the three teaching topics (in the order of M, F, E) shown in teaching plans reveals an upward trajectory in their convergence degree. Textbook analysis (section 4.3) indicates a progressive elevation in the academic level and numbers of mathematical calculations within these three topics, while the free space left by the topics for teachers in teaching design shows a decreasing trend. Additionally, a decline in the number of group experiments that necessitate student operation occurs, while there is an increase in teachers' explanations and exercises. There is a decrease in the incorporation of humanistic knowledge.

Discrepancies rise between teachers. Based on the teaching suggestions formulated in accordance with curriculum standard and textbook (CUT), teachers modify the teaching content and adjust the teaching structure by incorporating their instructional style and considering the evaluation requirements of open classes. The diversity in teachers' instructional styles is largely influenced by their assumptions about their teaching abilities and preferences. Oliver and Freddie tend to adopt a more didactic approach that demands high levels of students' concentration. Conversely, other teachers employ various instructional activities (group experiments, demonstration experiments, props and examples, and exercises) apart from lectures to allocate teaching time, aligning with students' attention span patterns.

4.5 Teacher interviews about teaching preparation

Seventeen teachers were engaged in semi-structured interviews to gather their perspectives on their content knowledge, knowledge of students and pedagogical knowledge that pertaining to the development of their Good Lessons (discussed in section 3.6.2 and 3.7.3).

The responses among teachers exhibited remarkable similarity, prompting the need to classify their responses into themes based on the theoretical framework. These themes were presented in Table 4.14, showcasing the raw data categorized under each group as it is, with an aim to capture the authentic perspectives and sentiments of the teachers. To ensure validity and reliability, only comments corroborated by two or more teachers are included. Additionally, reporting the topics to which these teachers belonged serves to indicate whether these themes were prevalent across topics.

Table 4.14 Examples of teacher answers in teacher interview categorized into content knowledge, knowledge of student and pedagogical knowledge

Dimensions	Teachers' responses in Topic M	Teachers' responses in Topic F	Teachers' responses in Topic E
Content knowledge	This lesson, as a whole, is a review lesson, and the concept is nothing more than magnetic phenomena and magnetic fields, these basic concepts of magnetism. (Jack) This lesson is to further study the magnetic field and magnetic induction line on the basis of the concepts learnt in lower-secondary school, and introduce the concept of geomagnetic field. The scientific method and reasoning, now the new curriculum standard is referring to the scientific method, the ability of scientific reasoning, but in fact it is not clear what it is, or it is not clear what the experts refer to scientific reasoning includes. In the teaching process, we consider how students understand knowledge, and design corresponding experiments according to textbooks, giving examples, analogy and other teaching methods. (Oliver) Since this lesson is a review lesson, it is also the introduction of a chapter, the concepts are students have been exposed to before, and it is easy to understand. Scientific method, there is nothing. It is mainly to tell stories to students, along the way to do patriotic education, curriculum standard included an unit that is called emotion - attitude - values. (Leo) In this lesson, magnetic field lines, Ampere's rule	The objective of this lesson is very clear, the force on a wire in a magnetic field. Force is a vector, direction, magnitude. Then introduce the application of this principle - ammeter, the scientific method may be the ratio definition method. (Freddie) I emphasised the control variable method in group experiment. (Charlie) I used conjecture and hypothesis, and experimental verification ran through the whole class, and induced multiple groups of experimental data to draw the final conclusion. (Oscar)	The concepts covered in this lesson include electric field, electric field strength, the definition and determination of electric field strength, electric field strength of a point charge, and the superposition of electric field strength. The overall knowledge is progressive layer by layer, requiring students to understand step by step and follow my pace. I also emphasised the ratio definition. (Ivy) Electric field, electric field strength, point charge field strength, superposition of field strength, there are a lot of content, all need to be calculated, in order to increase students' interest, I sacrificed some time on interaction. the superposition of field strength is too late to talk about. Consolidation is the main thing, as long as students can remember things after class. (Mia) The main thing is to let students know that the field strength does not relate to the amount of charge of the test charge. It is a vector, with magnitude and direction. This is the focus of this lesson, get that out of the way, the rest will follow. (Emily) The concepts follows the content of the textbook. The scientific method is the ratio definition, which is mentioned in the textbook,

	and the Earth's magnetic field are the main concepts to be introduced to students. The knowledge is simple and easy to understand, and it does not need to spend too much time to explain. As the first section of the magnetic chapter, the precautions on electromagnetic experiments need to be emphasised, which is helpful for students learning in the future. At the same time, the real presentation of experimental phenomena can impress students most. At the end of this class, I took the geomagnetic field as the content of understanding after class, and the geomagnetic field is also the content of understanding, and will not be tested on calculation. (Lily)		and scientific reasoning is not clear. (Hannah)
Knowledge of student	Students in lower-secondary school have learned the basic knowledge of magnetism, and they can also see the magnetic phenomenon in life. After understanding in advance, this group of students also have a preview before the class, and the knowledge is no longer strange to them. (Jack) This group of students I teach should have no problems with knowledge understanding. Without talking about it, they should be able to understand everything. (Sophia) This lesson is basically a review lesson, students have been exposed to the basic concepts of magnetism in lower-secondary school, and this lesson is nothing but those things (Leo).	The students should be very smart, and based on the relevant knowledge they have already been exposed to in lower-secondary school, this class should go smoothly (Ava) There are a lot of things for students to understand in this class. Based on what they have learned before about magnetic effects of current, I designed experimental demonstrations to assist students in understanding. This group of students are doing well, so there should be no problem. (Charlie)	There are a lot of calculations in this class, and the students are familiar with them. They are all ordinary people, and they are not said to be smart, but I have asked them to preview them in advance (Luna). Last time we talked about Coulomb's law, and it will be easier for students to understand it, the difficulty is to pay attention to the properties of the electric field strength, the definition, the determination (Daisy).
Pedagogical	The choice of teaching strategy is not critical, the	Experimental demonstrations are very	The class can be more interactive, such as the

knowledge	essential thing is to get the students to listen to you. We want to tell students that learning is vital, hence the cliché that so many people have told them. We have to say more practically. Exams are what they will face and feel essential at this stage. Tell the students: Now listen carefully, the test is going to be taken on this point, and the attention will be focused. But one thing, this does not work for excellent students, excellent students no matter whether they listen to the lecture or not, they can get great marks in the exam. Teaching these types of students is hard, challenging stuff that can grab their attention. (Oliver) For the selection of teaching strategies, we need to consider whether they can arouse students' interest, not necessarily useful or difficult. (Lily) We can give additional examples from everyday life, and examples that are close to everyday life will be more familiar to the students and will interest them. (Jack) Students in this age group are interested in some advanced and sophisticated technologies. They can't touch them in daily life, so there is a sense of mystery for students (Leo). Teachers should be familiar with the course they are going to teach. Like myself, before teaching this lesson I had study the content and consulted numerous other teachers' lesson plans. (Sophia)	important to help students understand concepts. (George) I've added demonstration experiments, group experiments, to my teaching so that it's not boring and avoids lecturing all the time. (Ava) The most important thing in teaching is that it cannot be flashy, and it needs to cut straight to the key points, and explain the concepts and methods that should be talked about clearly. (Freddie) Before teaching, the experimental equipment should be checked in advance, otherwise, the preparation is excellent, and the experiment wastes time and is also a stain on teaching. Each class lasts 45 minutes, and every minute is precious. (Charlie) Before teaching, we must think about how to speak in advance, what to use, but also to predict the possible emergency situation, and think of a solid solution, do not cram at the moment, delay time, that will give people a bad feeling. (Oscar)	history of physics to attract students to the class (Mia) If you want students to learn, you need to add more knowledge applications, that is, exercises, more practice, and students will naturally understand. (Ivy) The whole teaching needs to be complete and there should be a response before and after, otherwise students will not remember anything after listening to a lesson (Ella).

4.5.1 *Content knowledge*

'Textbooks, for better or worse, dominate what students learn...And teachers rely on them to organize lessons and structure subject matter' (Down, 1988). Interviews with seventeen teachers reveal that their understanding of teaching content, particularly the concepts embedded within it, is perceived as unchanging. This perception is evident in teachers' responses such as 'the content covered in textbooks represents the essence of what can be conveyed', 'while textbooks are designed for students, teacher's book is for teachers, utilize them to guide learning and instruction', 'mainly study textbook content, most of the expanded content is application knowledge' and 'teaching content primarily revolves textbook content.' From the perspective of these teachers, teaching content remains fixed. Even during curriculum reforms when new academic terminology is introduced into curriculum standards, there is minimal alteration to the knowledge scope covered in textbooks. This has a negligible impact on instructional practices. Drawing upon years of experience in teaching, these teachers have developed a profound familiarity with upper-secondary school physics knowledge network. Consequently, when presenting scientific methods during lessons, they integrate methods and reasoning presentation within teaching material organisation. To illustrate this point, an example from Oliver's interview is provided below.

Interviewer: What did you intend students to learn about scientific concepts and methods?

Oliver: the content shown in textbook, magnetic field, magnetic induction line and the Earth's magnetic field. You can't change that.

Interviewer: You mentioned the concepts that you covered in your teaching. What do you think about the scientific method or scientific reasoning?

Oliver: This is a review lesson. There is a chapter on magnetism in lower-secondary school. It's also the first unit of magnetism chapter. About scientific methods and reasoning... Now the new curriculum standard is referring to the scientific method and the ability of scientific reasoning, but in fact it is not clear what it is, or it is not clear what the experts refer to scientific reasoning includes.

Interviewer: As you said, the new curriculum mentions scientific reasoning, but it doesn't give you a clear explanation. So let me give you an example. Experiment verification, hypothesis, classification are all scientific reasoning. Did you consider including any of these into your teaching?

Oliver: Well, there are not many of them in this lesson. Most of the content is review, mainly lecturing, and not much about methods. When determining the direction of the magnetic induction *line, students are asked to make bold assumptions. In other lessons' teaching process, I consider how students understand knowledge, and design corresponding experiments according to textbooks, giving examples, analogy and other teaching methods.*

(Oliver, M5-I)

After years of teaching in high school, teachers' comprehension of knowledge has gradually shifted towards popular science rather than purely academic content. This shift primarily stems from the fact that popular science knowledge can be communicated effectively to students. Teachers possess the ability to transform intricate and abstract academic concepts into easily comprehensible forms that are applicable to real-life situations, thereby facilitating a more intuitive understanding and mastery of the subject matter among students.

In this lesson, I will use a song of Spring as the introduction to arouse students' imagination of spring and imagine the scenery of spring as some concrete things. Spring is an abstract noun, which we can associate with actual things, which is the embodiment of abstraction. Then electric field is the concrete name we give to abstract things that cannot be seen or touched. In this way, students can understand that the abstract and the concrete are related. This should also be a manifestation of scientific method.

(Daisy, E5-I)

This lesson uses the physics method of hypothesis and experiment. Before I do the demonstration experiment, I ask the students to guess what experimental results will look like, so that the students can look at the experiment with questions and remember it more deeply. Throughout the experiment process, I will also emphasise the norms of the experiment and convey the scientific method of physics experiment to students.

(Oscar, F4-I)

The content knowledge presented by teachers in their instruction primarily derives from textbook. Their understanding of knowledge is leaning towards popular science. Their considerations focus on effectively conveying this knowledge to students through language, often employing analogies as a commonly used method. However, teachers generally lack a clear comprehension of scientific methods and reasoning. When organising teaching materials to present instructional content, the consideration of scientific methods is integrated into the overall pedagogical approach.

4.5.2 *Teachers' knowledge of students*

The understanding of students stays at the level of the concepts learned. As had mentioned in section 3.5, seven teachers did not teach their own students, they came to Beijing to teach pre-arranged groups of 20 students, as part of the national project. Teachers can only make a preliminary judgment on the students based on the knowledge they have learned and their academic performance.

Students in lower-secondary school learned the basic knowledge of magnetism, and they can see the magnetic phenomenon in life. After asking their teacher in advance, this group of students have a preview before the class, and the knowledge is no longer strange to them.

(Jack, M1-I)

Last time we talked about Coulomb's law, and it will be easier for students to understand it, the difficulty is to pay attention to the properties of the electric field strength, the definition, the determination.

(Daisy, F5-I)

Teachers usually rely on experience and students' overall achievement as the basis for understanding students and adjust their teaching accordingly. Teachers have no time to take care of every student, and there are large differences among students. The class size is large. Usually, in one semester, one teacher corresponds to several classes which cover hundreds of students. In addition to teaching tasks, teachers also have to bear the administrative tasks assigned by the school, and teachers also have to take into account their families. Compared with these tasks that must be completed, spending time on understanding the students and constantly revising teaching plans for different audiences becomes meaningless.

We all need to prepare textbooks, prepare students, and prepare teaching methods, as we are taught in school. However, after working for a long time, we may inadvertently overlook certain steps and gradually develop our own teaching style. I know how to teach a group of students when I see them the first time. The misconceptions that come up in students are pretty much the same

(Oliver, M5-I)

You could ask the other teachers, we have to hold teaching and research meetings almost every day, almost have no time to care for the family. Students have the need for individual counselling to come to me, I will certainly give good counselling, but really do not have the time to understand every student, there is no need to do that.

(Ivy, E1-I)

After the exam results coming out, I will know the gaps, then, more exercises can fix them. New classes are usually less considered (the students).

(Leo, M4-I)

The design of the textbook and teacher's book take students' learning into consideration, and I will follow it. Usually, when the students show that they can not understand during the class, I will make adjustments.

(Freddie, F5-I)

Teachers' comprehension of students typically encompasses their prior knowledge and misconceptions.

4.5.3 *Teacher's pedagogical considerations*

For experienced teachers, pedagogical knowledge is ingrained in their expertise and cannot be easily explained. It is derived from years of practical experience. When discussing pedagogical knowledge, teachers often emphasise the organisation of instructional materials, effective time management, and strategies to enhance the engagement of students. Typically, the teaching sequence relies on textbook and teacher's book for guidance.

The choice of teaching strategy is not critical, the essential thing is to get the students to listen to you. We want to tell students that learning is vital, hence the cliché that so many people have told them. We have to say more practically. Exams are what they will face and feel essential at this stage. Tell the students: Now listen carefully, the test is going to be taken on this point, and the attention will be focused. But one thing, this does not work for excellent students, excellent students no matter whether they listen to the lecture or not, they can get great marks in the exam. Teaching these types of students is hard, challenging stuff that can grab their attention.

(Oliver, M5-I)

I usually teach according to the order of the textbook. This open class is based on the fact that the students have not yet learned the magnetic induction intensity. The teaching content needs to be changed accordingly, otherwise it will be difficult for the students to understand. Like that, the teaching task of this class is heavy. However, the experiment is still indispensable. The whole class must not only consist of lectures, the middle needs to be interspersed with experiments, activities, examples, so that the students are not bored. This lesson has added demonstration and group experiments. When the experiment takes up a certain amount of time, the corresponding exercise time is compressed.

(Ava, F2-I)

The general teaching methods of physics classroom are lecture, experiment (demonstration experiment, group experiment, inquiry experiment, video experiment, props), questioning, discussion, practice, self-study, review, as well as writing on the blackboard, preparing and debugging teaching media, organising teaching, and managing the classroom.

4.6 Conclusions and implications

This chapter analysed textbooks and teaching plans. In CUT, the language is concise. CUT contains patriotism education blended into the introduction of physics history and emphasises the use of mathematical tools to solve physics problems. There are relatively few exercises, and CUT is an extension of CLT in numbers of knowledge, so it cannot be well-matched with related physics content in higher education. This gives teachers and students the room to replenish related concepts, reasoning, examples and exercises. 'There is a limit to our life, but to knowledge, there is no limit. With what is limited to pursue after what is unlimited is a perilous thing.' (Tzu, 1991, p. 47) Zhuang Zhou lamented the helplessness of limited life towards infinite knowledge. It is indeed impossible for human beings to learn all kinds of knowledge in a limited life. Human beings are making knowledge expand, update and develop continuously. Education should cultivate this type of talent who understand methods and can learn and have original ideas. Physics has its unique advantages in such respect (Peng, 2000, p. 34). The current version of CUT has not reached this level, yet it provides a relatively complete knowledge framework without providing teachers with sufficient teaching resources (section 4.3).

Compared with AQA, the language in CUT is simple, and some knowledge appears in simplified expressions for students' understanding, such as the left-hand rule (see p100.). The left-hand rule in the CUT is a simplified version of Fleming's left-hand rule; it cannot reflect that the force is perpendicular to the current and perpendicular to the magnetic induction line (Ren, 2017). Regarding the inappropriate simplification of the language in CUT, some researchers have already questioned it (Li, C., 2015; Yang, 2020). Topic F content in CUT uses first person plural to push readers to do experiments, analysis, and get results instead of a third person statement, which narrows the space for readers.

Users of the textbook, especially teachers, should thoroughly research and analyse the textbook during teaching activities and grasp the important and difficult points and internal connections of content knowledge (Peng, 2009). From the teacher's teaching design perspective, teachers comprehensively considered the recommendations of the textbook, curriculum standards and the teacher's book and made changes following their characteristics and teaching context (section 4.4). The changes in the knowledge structure include the exchange of order and the deletion of content. For Topic M, as the introduction chapter of magnetism, Oliver, Sophia and Leo all add a certain amount of physics history and clarified their role, patriotism education. Oliver and Leo add exercises, Freddie in Topic F has added numerous exercises. The seven teachers in Topic E have added corresponding classroom exercises to strengthen students' understanding of knowledge. Teachers reorganised the knowledge according to different understandings of concepts and teaching focus. Among the three topics, the change in Topic E was the biggest. Six teachers split the content shown in textbook. The electric field lines and the uniform electric field were not included. Compared with Emily's teaching design, which contains all the knowledge, the other six teachers arranged more appropriate demonstrations, activities and exercises.

In the presence of the scientific method, the experimental evaluation method was mentioned in the instructional design, in which the variable-controlling method was used. In the teaching design of Topic M and Topic E, teachers planned to use the history of physics as teaching materials, analyse the discovery process of physical quantities from a historical perspective, and point out the process of physics development. The induction method and the ratio definition method were mentioned. Most teachers wrote down the physics methods used in the instructional design. Teaching methods should make physics methods explicit and use the knowledge they have learned before to help students form an effective knowledge network.

The analysis of teaching sequences finds that teachers follow the order suggested in the teacher's book, with only some minute adjustments. Teachers have added teaching materials, including demonstration experiments, activity demonstrations, exercises, worked examples, examples of application and physics history. (section 4.4)

Teacher interviews provided valuable insights into their perspectives on teaching materials requirements, curriculum standards, and the development of teaching designs, as well as their conceptualization of teaching design. Firstly, all interviewed teachers emphasised the importance of aligning their teaching with the prescribed teaching materials and curriculum standards. During lesson preparation, they ensure that the knowledge scope and structure adhere to the content outlined in the materials while making necessary adjustments to language expressions and providing relevant examples. Secondly, teachers consider students' academic backgrounds and primarily focus on building upon previously acquired knowledge. Lastly, when it comes to instructional methods, teachers predominantly concentrate on preparing teaching aids and designing experiments. While teachers possess an understanding of the required pedagogical concepts stipulated by curriculum standards, there exist numerous challenges in effectively implementing these principles into their actual teaching practises.

The teaching design did not include the teacher's teaching language. Therefore, through the analysis of classroom teaching record, the next chapter observes the teacher’s language expression, the presentation of the scientific method, the rationality of knowledge building, and the teaching process to explore the classroom's complete view.

Chapter 5 Data Analysis: How did the teacher teach in class?

Teaching is an instant art. In the classroom, you can do whatever you will and have rules.

-Leo

5.1 Introduction

This chapter draws up the semantic waves and sorts out the semantic context of the classroom discourse through the analysis of the selected classroom teaching videos. The semantic waves based on the relationship between language and context in classroom discourse are deconstructed. For each topic, this study collected five to seven classroom teaching videos (discussed in section 3.5) to analyse and study classroom teaching. Table 5.1 is the basic situation of seventeen classroom teaching videos (detailed information shown in section 3.5).

Table 5.1 Basic information about the seventeen classroom teaching videos

Topics*	Pseudonym of teachers	Gender	Teachers' original location	Code of Class	Class number**
Magnetic phenomena and magnetic field (M)	Jack	Male	Anhui	M1	1
	Lily	Female	Liaoning	M2	2
	Sophia	Female	Xinjiang	M3	3
	Leo	Male	Liaoning	M4	4
	Oliver	Male	Sichuan	M5	5
Force on the current-carrying wire in a magnetic field (F)	Charlie	Male	Jilin	F1	1
	Ava	Female	Sichuan	F2	6
	George	Male	Jiangxi	F3	7
	Oscar	Male	Zhejiang	F4	3
	Freddie	Male	Jiangsu	F5	8
Electric field strength (E)	Ivy	Female	Liaoning	E1	9
	Mia	Female	Liaoning	E2	10
	Emily	Female	Liaoning	E3	11
	Ella	Female	Liaoning	E4	12
	Daisy	Female	Liaoning	E5	13
	Hannah	Female	Liaoning	E6	14
	Luna	Female	Liaoning	E7	15

* M, magnetic field and magnetic phenomena; F, the force on the current-carrying wire in the magnetic field; E, electric field strength

**class number aims to give a mark of different classes of students. Teacher Jack and teacher Charlie taught the same class (1) of students with different topics. Teacher Sophia and teacher Oscar taught the same class (3) of students with different topics

5.2 The semantic waves of the classroom discourse

In Chapter 2, this study established a semantic wave structure based on the characteristics of physics knowledge and classroom teaching. Based on the established structure, this section analyses and compares the characteristics of the semantic waves of teachers teaching for the same topic. This chapter compares the semantic waveforms for three topics to explore similarities and differences. Finally, the common waveforms and characteristics of the semantic wave of physics classroom teaching are discussed.

5.2.1 *Topic M: magnetic phenomena and magnetic field*

Chapter 4 analyses textbooks and finds that most content in this topic is based on a review of the related concepts of magnetism learned in lower-secondary school, introduces the concept of magnetic phenomenon and magnetic field, and demonstrates the magnetic phenomenon and its application (section 4.3.2). The teacher's book and the teacher's instructional design show that the content of this topic does not involve mathematical operations, only physics concepts (section 4.4.1). According to the identification elements of the semantic wave (theoretical framework, section 2.2.4 and 2.3.5), the maximum amplitude of the waves in this topic is only around II, and do not reach III or IV.

The first part of this section takes Jack's teaching analysis as a detailed example of the analysis process. The second part analyses and compares similarities and differences of the semantic wave characteristics of the five teachers of Topic M, and then summarises the characteristics of topic one waveform.

5.2.1.1 **Jack's teaching process**

At the start of the lesson, Jack says 'hello' to the class with the students standing up and responding 'hello' to him. This is a traditional Chinese class ceremony[12]. The surface word is 'hello', but this is a command that aims to focus students' attention on the class as a tool of classroom management. A lesson should be a social activity that has a pattern of structure (Lemke, 1990). The participants should share a common sense of the structure of the activity, including what is happening and what comes next (Lemke, 1990). The specific start of Jack's class is saying hello and following a brief introduction of the topic of the class:

1 *T: We are going to learn about magnetic phenomena and magnetic fields together,*
2 *so before we learn about magnetic phenomena, let's look at a video.*

---

[12] Normally, the monitor of the class says 'stand up', the whole class will stand up, then the teacher will say 'Hello everyone', students respond 'Hello teacher' and bow to the teacher together.

(Jack, M1-O)

This initial sequence of discourse is critical in setting the scene for class. A declarative typically expresses a statement or giving information (Webster, 2019). The introduction of the title of the class implied the learning target: knowing and understanding the Magnetic phenomena and magnetic field. The inter-clausal logico-semantic relation that exists in the sentence is the taxis relation. The participant of this material process is 'we' which is used to shorten the distance with students and indicate that teacher and the students are together. The 'you-and-me' type, with we or let's, realises a suggestion (the response form is Yes or No), something that is at the same time command and offer (Halliday & Matthiessen, 2004). The specialised terminology that appeared in this sentence is only the terms' magnetic phenomena' and 'magnetic field' without any explanation, symbol and equation. Except for the expression of the terms, there is no nominal expression in the sentence. In sum, this sentence concisely states the concepts that will be learned in this lesson. Therefore, the amplitude of the semantic wave of this part is around I. As the terminologies are mentioned, it is a rising waveform based on the hello words.

[A Cartoon played on the screen: there are three cartoon characters, a little pin (L), a stone (S, natural magnetite specimen), a bar magnet (B). L: I'm the little pin, today's weather is so great, let me have a walk. [fell in a hole on the ground] Oh, help, help. Who can help me! S: I am coming, I will help you. B: No, you can't, let me help you. [S and B fight with each other]]

(Jack, M1-O)

This cartoon is a visual material that is used as a primer of the lesson which raises the question that which one could attract the metal pin. The video is an instructional activity to set a scene and a classroom management to pool students' attention in the lesson. The language in the cartoon is our everyday language, which does not contain any proper nouns and complex sentence patterns, and there is no improvement in a tone such as commands. Therefore, the semantic wave shows a downward trend and remains in area I.

After the display of the cartoon, the lesson goes to the next step which is a typical pattern in modern education, a special form of triadic dialogue Initiation-Response-Evaluation (IRE) (Lemke, 1990). Jack asks students' ideas about the question:

3 *T: They fight for 'little pin', then, who can save the 'little pin'? What do you think?*

4 *(1)*

5 *Please.*

6 *[Point to student 1]*

7 *S1: I think it's the one with NS pole can [[save the 'little pin'.*

8 *T: Why?]]*

9 *S1: We had learnt in junior school that it can attract metal [[objects.*

10 *T: Oh, it can attract]] metal objects, right? Perfect, agree with him?*

11 *[Nodding]*

(Jack, M1-O)

The language style continues the children's style in the animation with a personification (the 'little pin') to draw a closer relationship with students (M1-I). The question after the video is aimed to push (nominate a student to answer) the student to think. The overlap in the conversation indicates that the question asked by Jack is to confirm rather than ask. He has pre-defined the answer and seemed to take control of the whole class through his actions. IR(FR)E is a specific pattern in classroom discourse. The teacher is not asking for information, but testing to see if the student knows it. Not every teacher question proceeds as teacher preparation for that question, but many are, and everyone could be (Lemke, 1990). In Jack's design, students have known that a magnet could attract metal materials; thus, the answer to the question should be the 'magnet'. The process of the question sentence is a mental process that asks for students' thinking and knowing. Then Jack repeats the student's answer and gives a positive evaluation 'perfect' to end this triadic dialogue. After the question, Jack pauses and points to student 1. The short pause marks Jack's silence which aims to give students time to think of the question and hands up to answer it. Within the short pause none of the students raised their hands, Jack points to student 1 to answer it. To see what happens during the lesson is not only the teacher's words, but the teacher does. Specifying a non-volunteer student to answer the question means that it is not as the question asked, 'what do you think', but testing whether the student knows the knowledge behind the teacher question. After getting a satisfactory answer, Jack designs a group activity to let the students find the answer themselves. Another thing to note is that as student 1 answers, Jack begins to ask and repeat. On the one hand, Jack is certain that the student knows the 'standard answer' of the question and 'guides' the student to answer it. On the one hand, it is a manifestation of the right to speak and the control of time.

Since the student’s answer contains physics terms and laws (NS pole, it can attract metal), the semantic wave rises to area II.

T: Well, today we invite the three main characters, then please do it yourselves, to verify your guess through experiment, let's start.

(Jack, M1-O)

The subject of the start of the sentence Jack used is 'we'. The appearance of the 'you and me' pattern foreshadows entering another teaching activity, in addition to the role of closer distance with students.

With the video playing, the question would arise naturally. Who can save the little pin? The students' answer must be the magnet. Because they have learnt basic knowledge in secondary school. However, they do not know, it is not a real magnet, and the stone is not common. Then, the group experiment will give them an opposite result. Students will wonder what the matter is. With this question in their mind, students will be more severe in further study of this lesson.

(Jack, M1-I)

Setting up cognitive conflicts with a teaching design makes the class live. Jack's class is teacher-led in form and considered the student's situation in teaching design.

In sum, within the two minutes introduction part of the lesson, only terms exist in the dialogue. Besides, there are no nominal groups and no passive voice. Therefore, the language of this excerpt could be characterised by low formality which allows easier access. The framing is floating that most of the sentences are interrogative, which is marked as moderate. The interaction in the lesson follows the IRE pattern and specifying students to answer the questions. Jack uses the first two minutes to manage the classroom, introduces the learning objectives and sets up cognitive conflicts. The whole structure of the two minutes is introduction activity (cartoon) – teacher question (IRE) – group activity – teacher question (IRE). Except for the student’s answer reaching area two, Jack’s discourse remains around area one during the introduction phase of teaching.

Jack's class's main task aims to make students experience the magnetic phenomena and magnetic fields through the demonstration experiment and group experiment.

1 *T: I want to know the appearance of the magnetic field existing around it.*
2 *What can we do to study the distribution of the magnetic field around it?*
3 *(2)*
4 *T: Can you say something about it?*
5 *[Point to S2]*
6 *S2: Use iron filings.*
7 *T: We can study with iron filings, right? Let's explore the distribution of the*

8 *magnetic field around it.*

9 *[Operating screen to show the demonstration experiment]*

10 *T: Here are iron filings, and we're going to put some iron filings around it.*

11 *Actually, teacher originally wanted to use this to do the experiment.*

(Jack, M1-O)

The subject in line one is 'I' with a mental process to open a new conversation, the distribution of the magnetic field. Then the teacher question is followed, and the subject change to 'we' to involve the students in the conversation. The student's silence gives Jack a signal that they might not understand how to answer. Jack uses the nature of the magnetic field as a reminder so that the student can think of the electric field learned earlier which is an invisible matter. The method should be similar to the one in studying the electric field. Then the Jack nominates a student to answer, gets the correct answer and returns to a triadic dialogue pattern. Here, it is doubtful whether the guidance of the Jack works. After the Jack prompt, there is none of the students raise their hands to answer the question. Therefore, Jack changes calling for a volunteer to nomination. The question is '*what can we do to'*, and the answer is what we should use to; the answer is not consistent with the original question. Jack repeats the student's answer as a positive evaluation and advanced to a demonstration experiment. The subject in line 7 was 'we'. As in the introduction part, using we or let's would mean that the lesson moves to the next activity. Jack explains the equipment and operations while doing the demonstration experiment. The subject of the sentence on line 11 is 'teacher'. In this excerpt, Jack uses 'teacher' as a mark to introduce a new hypothesis. The previous conversation had reached a consensus. At this time, Jack uses 'teacher' instead of 'I' to propose a new hypothesis from a third-party perspective to trigger new discussions. Using 'teacher' instead of 'I' is a symbol of power. It is implied that this new assumption is correct. The latter question is asking why it is correct, rather than whether it is correct.

1 *T: Does anyone agree with my point of view?*

2 *(3)*

3 *Is there any opinion?*

4 *(2)*

5 *Well, then, why do you choose iron filings?*

6 *[Point to S2]*

7 *(3)*

8 *S2: The iron can reflect the distribution of the magnetic field,*

9 *while the magnetic needle cannot.*

T: The magnetic needle cannot, iron filings can be used to study magnetic field distribution of a region, right?

[Sit down]

T: Well, what do you think, it's okay.

[Point to S3]

(3)

S3: I think compared with iron filings, the small magnetic needle can only study a point of the field, and can only study the direction, the distribution of magnetic field cannot be studied, density, size also cannot be studied.

T: Perfect, sit down, please. He says iron filings can be used to study a magnetic field's distribution, and he said small magnetic needles can be used to study a magnetic field's direction. If we put the two together, we can study the whole appearance of the magnetic field, right? Is that right? OK, now, we'll use iron filings to study the magnetic field around this mysterious magnet.

(Jack, M1-O)

When the silence returns, Jack changes to nomination. This time Jack asks student 2 who answer 'iron filings' to elaborate his answer instead. There is an IRE pattern; Jack does not receive the full correct answer. Jack gives students time to think more about the question without giving further guidance. Then, Jack nominates and encourages student 3 to answer the question. Student 3 elaborates the answer of student 2 and mentions the direction of the magnetic field. The magnetic needles could indicate the direction of the magnetic line.

From the above two excerpts, Jack tends to stick to his flow of teaching. The answer to line 2 in Jack's preparation should be magnetic needles instead, which is not the correct one in his lesson.

In junior school, some should have seen the experiment done with iron filings, some of them might not. Magnetic needles are typically used to show the distribution and explore the direction of the magnetic field.

(Jack, M1-I)

The order of preparation in advance should be: teacher question, students answer 'magnetic needle', and then Jack guides 'a magnetic needle can only study the direction of the magnetic field at one point, how to study the distribution of the entire magnetic field', students answer iron filings. Jack does not make adjustments when encountering unexpected answers but inserts the skipped content into the teaching process slightly rigidly. This inflexible performance could be a lack of understanding of the students, and an arrogant expression. Students from a better school that more likely had seen the experiment done with iron filings, thus they had already known that iron filings are used to display the distribution of magnetic field, and a magnetic needle is used to indicate the direction of the magnetic field at one point.

Then, Jack continues to do the demonstration experiment and ask the student to report the phenomena with IR(FR)E pattern to push and guide the student in improving the report. Finally, Jack summarises the experiment and writes the keywords on the blackboard for students taking notes. During the demonstration, the screen shows the demonstration synchronously to ensure everyone could see it.

Within the five minutes demonstration, only terms exist in the dialogue. Besides, there are no nominal groups and no passive voice. Therefore, the language of this excerpt could be characterised by low formality which allows easier access. The framing is strong in that most of the sentences were imperatives. Most of the sentences are the material process to describe the behaviour of Jack, which implies that these experimental operations are the rules when experimenting. Teacher gestures were used to manage the classroom involving nomination and ending up a triadic dialogue.

The interaction in the lesson followed IR(FR)E pattern and nomination. The activity structure is teacher question - student hypothesis – elaboration - demonstration experiment – observation – summary. Almost ten minutes have passed here. After analysis and classification, the semantic wave of classroom discourse in these ten minutes is drawn as shown in Figure 5.1. There are slight ups and downs, most of which are concentrated in the range of I-II. The highest point appears in the introduction to the experiment of studying the magnetic field distribution, using more physics expressions, making the discourse more rigorous. The lowest point appears in the greeting section at the beginning of the class

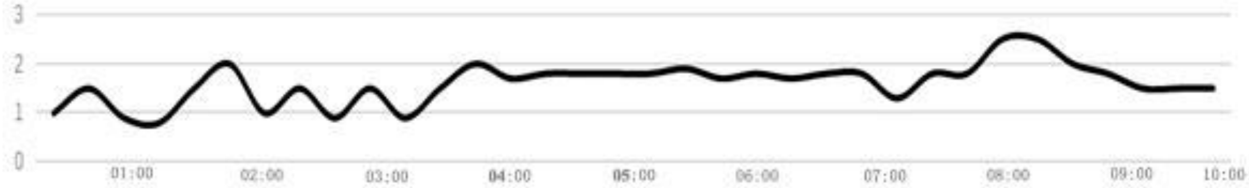


Figure 5.1 The semantic wave example of Jack's teaching (the first ten minutes)

The next activity is a group experiment. When students experimenting, Jack walked around the class and guided their operation.

1 *T: It could move to the middle.*

2 *You could cooperate.*

3 *It could be spilt more.*

4 *This area needs a little bit more, and here, and then gently tapping.*

5 *You need to see the direction,*

6 *You could use the magnetic needle to see its direction, and you could record it.*

7 *Trace it.*

(Jack, M1-O)

The language could be characterised by low formality without any terms or nominalisations. The sentences are imperatives so framing is high. As far as the conditions for the listener's involvement promoted by this text is concerned, it can be concluded that since most sentences use the second singular person, the combined value of framing is strong. Consequently, the overall value of the framing implies by this discourse tends to be strong. When Jack is guiding the student to experiment, there is no communication. The guidance given by Jack is command instead of a suggestion.

In sum, the main task in Jack's lesson follows a cycling activity structure: teacher question - student hypothesis – elaboration - demonstration experiment – observation – group experiment – display results – summary. The reasoning sequence that the main task expressed was cycling: Hypothetical Modelling - Experimental Evaluation. The semantic wave of classroom discourse is fluctuating (shown in Figure 5.4). At the beginning and end of the class, Jack reduces the density of professional words in the language, and start and end the entire class with the language in daily life. In the introduction part, Jack describes the video content in everyday language and asks questions. The video personifies iron pin, bar magnet and stone-like natural magnet to create scenes to arouse students' interest. When Jack asks questions, he simplifies the question and tries to use fewer specification nouns. Everyday language is used in classroom management. The whole process is more like an experienced process, using classroom activities to string together the entire class and use more life-oriented language to guide students' answers.

5.2.1.2 The characteristics of other teachers' semantic waves

This section discusses the other four teachers' teaching discourse and relative semantic waves.

The concepts of magnetism have been learned in lower-secondary school, and can be contacted in daily life. After the props demonstration, **Lily** asks students to talk about the magnetism phenomena in daily life. When the student mentions the access card, Lily tries to describe it as a magnetic card, but the student disagreed. The student might not know how it works. Lily could directly cite the principle of magnetic lock and ignore whether the tool is a key or a card. In this way, it does not directly deny the student but can transition to the magnetic phenomenon in life. Lily directly denies the student's answer.

T: In fact, there are many magnetism-related phenomena around us. Then please recall, what phenomena do you know that is related to magnetism around you? If you have any ideas, raise your hand.
S: Magnets can attract things something else like iron.
T: Magnet, good, and any other opinions? You.
S: The security doors in some communities seem to use magnetic suction, and then use the key to open them.
T: Use key? What kind of key?
S: Just the normal key, I am not sure, but I think it's supposed to be a magnetic one
T: Sit down please, It might be a little bit like the kind of room card we use at the hotel, isn't that right? Is it what do you mean? A magnetic card.
S: Just the normal key.
T: Normal key? That's the unlock function. Other students?

(Lily, M2-O)

Contrary to Jack, Lily uses more professional and rigorous language to set an example for students, so it increased the density of professional words when asking questions to some extent. But in classroom management, Lily uses everyday language to issue instructions and make demands to students. When the students were doing group experiments, Lily instructs the students to use the everyday language without too much professional vocabulary, but directly tell the students how to operate.

From the use of language, Lily divides the classroom into two parts, formal teaching and classroom activities. A formal classroom is to maintain a certain degree of professionalism when speaking on the podium, hoping to improve students' language rigour. Lily adds an introduction of the front and side views of the electric field lines in the classroom, and \repetitively emphasizes key concepts and words. Interestingly, Lily can realise that the specific words are hard to understand, she chooses to speak them out without explanation. As Lily said that this lesson is the basic content of the magnetism chapter. What students need to do is to remember the meaning of these concepts accurately and clearly. The exam will only test some simple content (M2-I, section 4.5). Therefore, Lily does not explain them but repeats them several times to deepen students' impression or memory of concepts. Classroom activities are reflected in classroom management and group experiments. Lily uses a life-oriented language that students better understand. The language of lectures and activities are different. From the semantic waves, it can be seen that the waves of the classroom activity are at a lower position than the waves of the lecture part.

In conjunction with the teaching plan of Lily in the previous chapter, Lily has not completed the content of her design, and spent a long time in group experiments. It may be because Lily uses high-density specifications in her formal teaching. The problems that students could not understand were exposed when doing group experiments, and Lily needed to answer one by one, which was a waste of time.

Similar to Lily, **Sophia** uses everyday language for classroom management, and for guiding students when doing group experiments. The difference is that Sophia does not pay attention to the rigour of the language when she is instructing students to do experiments, she even directly replaces the students in the experiment operation without giving explanations. It indicates that the student experiment designed by Sophia is not designed to help students better understand knowledge but to design classroom activity itself. Sophia's speech in the class is maintained at a professional level, which well demonstrates her adequate preparation before class. She starts and ends the class with lectures, filling in the blanks with the designed tasks. Sophia pays too much attention to the fluency of the classroom and tries her best to follow the pre-designed process. Her class ignores the students.

1 *T: ... Is the magneticity of all parts of it the same or not?*

2 *S: I think it should be the same.*

3 *T: A magnet, each area on it, its magnetic strength is the same*

4 *S: Is that, you mean its magnetic field?*

5 *T: A magnet, each area on it, their ability to attract iron, cobalt and nickel materials all the same?*

6 *S: The magnet is the same, almost the same. The magnetic field strength is the same within one magnet.*

7 *T: Their ability to attract iron, cobalt and nickel all the same?*

8 *S: Separately the ability to attract iron, attract cobalt and attract nickel might be different.*

9 *T: A magnet, is the magneticity of all parts of it the same or not?*

10 *S: Yes*

11 *T: Well, please sit down, are you all agree with him? You, I saw you were laughing at him ...*

(Sophia, M3-O)

When one of the students gives a wrong answer, Sophia repeats the question again and again, without further explanation, or changing the way of asking questions. Combined with the fact that

Sophia will complete the experiment on behalf of the students, all these shows that Sophia's teaching purpose is to hope everything sticks to her plan, not to teach knowledge. Sophia's teaching design draws on the other teacher's existing teaching design. Before this class, Sophia had pre-taught 8 times in her class and practised countless times by herself (M3-I). Such repeated practices have made the teaching plan deeply imprinted on Sophia's brain. Unfortunately, it is only imprinted on the brain and not integrated with her knowledge. The teachers trained in this way can reach the level of excellent teachers in the teaching language within a short period, but the ability to respond on the spot requires time training and continuous self-reflection.

1 *Current and magnet can generate magnetism,*
2 *The magnetic field's nature is substance.*
3 *Magnetism and electricity affect each other,*
4 *Magnetism and electricity can be converted into each other.*
5 *There is physics everywhere in life,*
6 *As long as you pay attention, you will learn.*
7 *I use my mind to understand physics,*
8 *Apply what you have learned and you could travel around the world.*

(Sophia, M3-O)

Sophia adds a self-compiled 'poem' at the end of the class, or more like a jingle, which is easy for students to remember and is a highlight of the teaching design for the evaluation program.

As mentioned above, many of **Leo**'s languages and designs are the same as Sophia. Leo's class seemed more comfortable, and Leo cooperates with students more smoothly. Leo's class is his class, and he knows his students much well. With almost the same teaching process and discourse, the progress of the class is more smooth than the Sophia's. Leo would not intervene students in the process of doing group experiments and lets students explain their experimental process in front of the class. On the one hand, Leo has more experience in teaching as the long working time; on the other hand, Leo has a better understanding of the students he faced. From this point of view, the knowledge of students is very important for teachers' classroom teaching. Another difference from Sophia is that Leo repeats the demonstration experiment twice to ensure that the students can see the experimental phenomenon. This should be regarded as the experience of the experienced teacher.

The teaching plans and the designed teaching language of Sophia and Leo are similar, and their semantic wave diagrams are similar (as shown in Figure 5.2). It shows that the semantic wave can show the teaching process accurately, which is further analysed in the decomposition of the semantic wave in the next section.

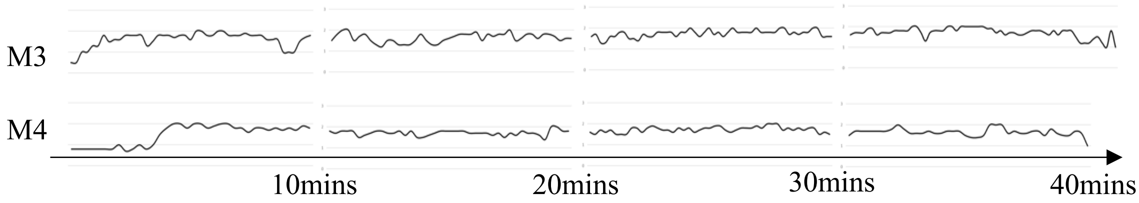


Figure 5.2 The comparison figure of semantic waves of Sophia (M3)'s and Leo (M4)'s class

Oliver, unlike the previous teachers, does not design any classroom activities during the whole teaching process and fills the whole class with a lecture. The opening of his class is unique, it is a common phenomenon in China, which starts with talking about the exam.

Today, after learning this chapter, we will know how to use our hands. We can see that some students are using both their left and right hands during the exam. They don't know which hand to use. After you learn this chapter well, you can know which hand to use, so you must listen carefully. If you don't learn this content well, the exam will make you feel very painful to take out both hands and don't know which one should be the right one. If you don't know which hand to use during the exam, you could only grab my hair. So, after the exam, your hair will be gone.

(Oliver, M5-O)

Oliver tells students in witty language that the content of this lesson is the key and difficult point in the Gaokao (the Chinese college entrance examination), and students need to study carefully and take notes. In Oliver's class, the professionalism of language is a bit erratic. Oliver uses professional physics language to explain the physics concept, and even read the original text in the textbook. In some explanations, the metaphors made to make students better understand were very life-like and not scientific.

The magnets interact with each other through the magnetic field, so the magnetic field is equivalent to a medium. These two magnets are like a man and a woman. What is the magnetic field? Matchmaker, Yue Lao, who lead the red line.

(Oliver, M5-O)

Oliver makes the metaphor, the interacted magnets and magnetic field are like a pair of blind daters and a matchmaker, which separates the magnetic field and the magnet into two different individuals. Oliver asks that if we hollow out the magnet, what the magnetic field inside the magnet would be like. If the magnet is hollow, the magnetic field would be different. These are all scientific errors and should not appear in the classroom.

The process of Oliver's class is to give physics concepts, urge students to take notes, and then gives his 'personal' explanations. As a natural science, physics is an objective description of nature. Adding teacher's subjective interpretation in the physics class might lose the characteristics of physics. An explanation is necessary, it is necessary to pay attention to the logic and scientific nature of the explanation. This is a cohesion problem that exists in the Chinese classroom. As a teacher said 'remember it first, you need to use it in the exam, and you do not need to understand it now. If you want to study physics when you go to university, what we're studying may be wrong'. This sentence is not completely wrong, to some extent, it is pertinent, and should not appear in physics class. The physics classroom is not just to teach students how to pass the exam, but to understand the corresponding physics knowledge. Through the brain's processing, students can finally reach the conceptual transformation to form their knowledge, not just remember the language.

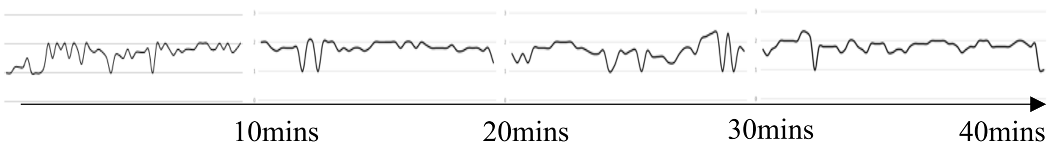


Figure 5.3 The semantic wave of Oliver's teaching

In Oliver's teaching, the appearance of these self-assertive metaphors makes the semantic waves have greater ups and downs than the other four teachers in topic one (shown in Figure 5.3). One sentence is talking about a physics concept or a physics law, and in the next sentence, it will appear as non-scientific and life-oriented terms. Such ups and downs can enliven the classroom atmosphere and attract students' attention (M5-I). The unscientific nature of the metaphor will affect students' establishment of their scientific concepts and knowledge. In the trade-off between fun and science, there are things worthy of consideration by teachers and educational researchers.

5.2.1.3 The characteristics of semantic waves in topic M

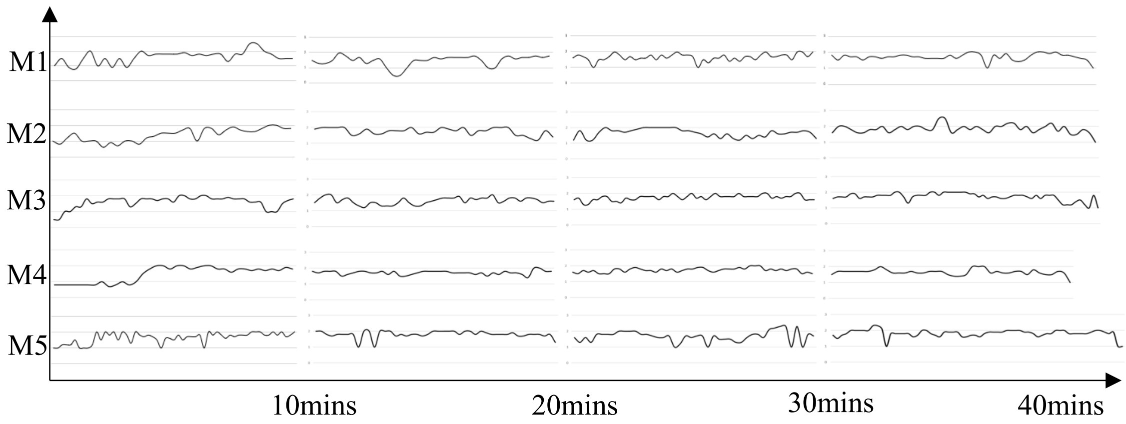


Figure 5.4 The comparison figure of semantic waves in Topic M

What the five teachers of Topic M have in common is that they all use a more life-oriented language in classroom management. Except for Oliver, they have designed various classroom activities in the classroom, such as group discussions, group experiments and demonstration experiments. The difference is that Jack uses easier-to-understand language to ask questions and guide students to understand and further think about the problem, like supporting students to study, Lily tends to use her language rigour as a role model for students while students touch the scientific content. Sophia and Leo tend to maintain a certain degree of language rigour and scientific and make appropriate adjustments at some point. Oliver adds some of his interpretations in the classroom, which would cause the rigour and scientific of the language cannot be guaranteed. The students' responses in class indicate that Jack and Leo's classes proceeded smoothly, with increased student engagement. The students demonstrated relatively standardized and clear language, as well as a relatively accurate understanding of physics concepts. They engaged in appropriate teaching activities that facilitated critical thinking and comprehension. In contrast, Lily and Sophia's classrooms showed lower levels of student activity, likely due to the dense professional terminology used which hindered their understanding of the material. Oliver's classroom appeared lackluster, with some students even appearing sleepy during the lesson. The use of dense professional terminology mixed with the teacher's interpretation may have contributed to this disengagement. While metaphorical language was employed, it did not effectively enhance knowledge retention among students. Additionally, the teacher's tone was perceived as imperative by the students, potentially impacting their overall learning experience. After a lesson, the only thing left to the students might be the words in the notebook.

As had mentioned in the previous section, the description of the magnetic field's nature is the basis for learning electromagnetic knowledge in the future (Ke & Ma, 2016; Peng, 2009). This topic introduces the underlying magnetic phenomena, magnetic effects, and geomagnetic fields based on relevant knowledge taught in secondary school (MoE, 2017b; Peng, 2009). The maximum amplitude of the wave is around II. The semantic wave of Topic M fluctuates between 0-III. According to the changes in the classroom content, the waveform jumps in different intervals. Semantic waves are mostly concentrated around II and drop to interval I at the beginning and end of the class and other limited-time points. It shows that classroom discourse is mostly focused on the explanation of abstract concepts and laws. The occasional life-like language is used to visualize concepts or conduct classroom management.

5.2.2 *Topic F: force on the current-carrying wire in a magnetic field*

Unlike Topic M, Topic F involves physics formulas and mathematical calculations, so the semantic waves fluctuate between 0-4. The five teachers' teaching objectives are all set according to the curriculum standards, and there are slight discrepancies in the teaching outcomes. All five teachers use experiments to demonstrate the physics process. The objects of this topic are clear. The direction and magnitude of the Ampère force and the left-hand rule for determining the direction of Ampère force should be the main content. The basic teaching process of this lesson is to demonstrate the experiment, define the Ampère force, guess the influencing factors, explore the magnitude and direction of the Ampère force, introduce the left-hand rule and apply it, and summarise the knowledge points. The designs of the teaching sequences of the five teachers are similar. How do different teachers use language to express in a class when the teaching content is highly concentrated? This part takes Freddie as an example. Freddie's speech fluctuates a lot, his teaching time is the longest, and the content is the most appropriate to the content of the textbook. The following section focuses on analysing the discourse characteristics of the other four teachers, and finally summarizes the waveform characteristics of the Topic F classroom discourse semantic waves.

5.2.2.1 Freddie's teaching process

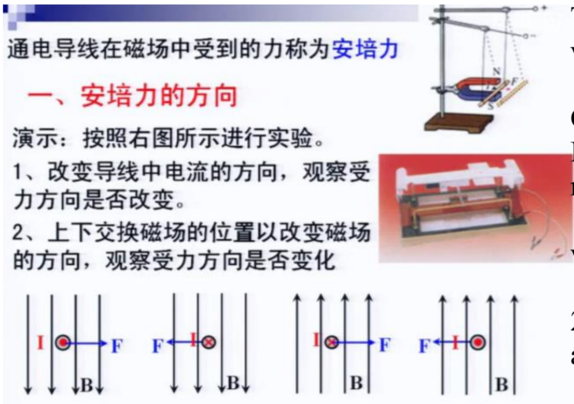
After the greeting part, Freddie reviews the content of lower-secondary school learning content, which leads to the definition of Ampère force. In the course of the explanation, Freddie combines the diagram to introduce to the students the direction of the current and the magnetic field involved in the determination of the direction of the Ampère force. In the shown part below, the semantic waves fluctuate between II and III, which is the fluctuation between the illustration and the verbal introduction.

T: ...Through the previous study, we know that the current-carrying wire is subject to force in the magnetic field. In order to commemorate Ampère, we call this force the Ampère force. So today we will learn about the Ampère force, learn its direction *and magnitude. First, let's learn the direction of the Ampère force.*

[Blackboard: 1. The direction of Ampère force]

So what are the factors related to the direction of Ampère force? Let's do experiments to explore.

[Slide]



The force received by the current carrying wire placing in the magnetic field, is called Ampère Force.
One, The direction of Ampère force
Demonstration: Experiment as shown on the right
1. Change the direction of the current in the wire and observe whether the direction of force changes
2. Swap the position of the magnetic field up and down to change the direction of the magnetic field, and observe whether the direction of the force changes

Figure 5.5 Freddie's teaching slide

Ampère force demonstrator, you can see that this is the NS pole, and there is a uniform magnetic field between them, a uniform magnetic field. This is a metal rod. When it is connected to the power supply, there is an electric current in it, electric current. Students, let's take a look, which is the direction of the magnetic field? Which way?

SS: Downward

T: Down, right? The direction of the magnetic field is downward.

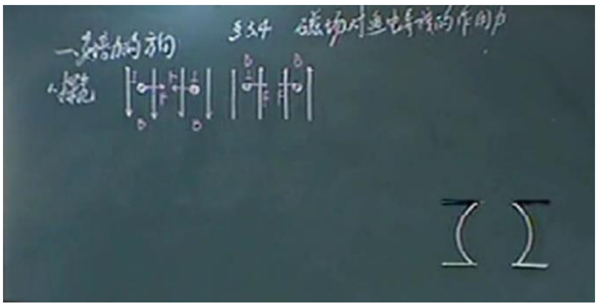


Figure 5.6 Freddie's blackboard writing

[Blackboard: Mark the direction of the magnetic field]

We can see that, after putting the metal rod in, what do you see? A cross-section of a wire, cross-section.

[Blackboard: Draw a wire]

When we turn on the current, turn on the current, we can see from the big screen, this is the positive pole, can we see it? This side is the positive pole, and this side is the negative pole. Then after the current enters in this way, the current flows in from here, flows in from here. Then if we look at this picture, look at this picture,

24 *the red one is the positive pole, and the black one is the negative pole. After the*
25 *power is turned on, does the current flow in or out? flow in, flow from here to here,*
26 *right?*
27 *[Blackboard: Mark the current direction]*
28 ...

(Freddie, F5-O)

During the first eight minutes of the lesson, except for a whole-class interaction, Freddie is always lecturing without any interaction. The lack of interaction may cause the disconnection with the students. After all, the object of the lecture is the student, and the content of the lecture is the information to be conveyed. Here, Freddie deepens students' understanding and memory by repeating keywords and combining images to explain. Freddie repeats the keywords twice (shown in lines 18, 25-26, 29, 31, 33) when they appear to ensure that students can hear them clearly and can take notes. Before the demonstration experiment, Freddie introduces the experimental equipment in detail. The schematic diagram of the experimental equipment and the experimental process is displayed on the slide (shown in lines 8-16 and Figure 5.5). In the process of experimenting, Freddie talks and paints, and finally shows the final comparison chart on the slide to deepen the students' understanding.

1 *T: ...Then, through the experiment, let's analyse, what are the characteristics of the*
2 *direction of Ampère force? What relationship does it have with the direction of the*
3 *magnetic field and the direction of the current? Sun*
4 *Sun: Perpendicular to the direction of the current and perpendicular to the*
5 *direction of the magnetic field.*
6 *T: It is perpendicular to the direction of the current and perpendicular to the*
7 *direction of the magnetic field, right? OK, please sit down.*

(Freddie, F5-O)

In interacting with students, Freddie occupies the right to speak. Freddie's questions are limited and take the form of directly designating students to answer the questions. Freddie sets up informative guides, for example *'what are the characteristics of the direction of Ampère force? What relationship does it have with the direction of the magnetic field and the direction of the current?*' (F5-O, line 1-3) Freddie limits the problem to the relationship between the three directions. Sun's answer is accurate.

8 *T: ...Can you express this relationship in a concise way? Ting*

Ting: The direction of the Ampère force is perpendicular to the direction of the current and the direction of the magnetic field

T: Well, they are all perpendicular. What law does the direction of the Ampère force, the electric current and the magnetic field follow?

Ting: The three of them are perpendicular to each other.

T: Well, what kind of law do they follow?

[Ting lowers his head and flips through the textbook]

T: Well, follows the left-hand rule that we are going to learn. Okay, what is the content of the left-hand rule?

Ting: [Hold up the textbook and read] Extend the left hand so that the thumb is perpendicular to the other four fingers and all are in the same plane as the palm; let the magnetic induction line enter into the palm and point the four fingers in the the direction of the current, then the direction of the thumb is the direction of the Ampère force that the current conducting wire current-carrying wire experienced in the magnetic field. This is the left-hand rule for judging the direction of force on a current-carrying wire in a magnetic field.

T: Um, ok, please sit down.

(Freddie, F5-O)

When Freddie further wants to elicit the left-hand rule, a problem that exists in Sophia's class appears. The students do not know how to answer the question. Teacher and student conduct two rounds of repetitive questions and answers (shown in lines 8-15). Finally, Freddie chooses to give the left-hand rule directly and asks Ting to read aloud the definition of the left-hand rule written in the textbook (shown in lines 16-24). During the answering, Ting keeps looking down and flipping through the book (shown in lines 15, 18). She tries to find the correct answer in the book. It loses the meaning of the question to a certain extent. Questioning in class is not to ask students to extract the correct answers from the book, but to follow the teacher's explanation. Ting's performance shows that she is eager to give the teacher a correct answer instead of expressing her understanding. Freddie agrees with this phenomenon. Freddie believes that concepts need to be remembered before they can be understood. It likes the Chinese idiom, 'read the book hundreds of times and you would understand what it means'. However, Confucius said that 'learning without thinking leads to confusion; thinking without learning ends in nothing'. If you read blindly without thinking, you will not be able to use the knowledge reasonably and effectively because you cannot deeply understand the meaning of the books, and you will even get confused. And if you blindly imagine and do not study and delve into reality, you will end up building a tower on the sand and gain nothing. Freddie's expression can be understood as Freddie believes that in 45 minutes, students are difficulty forming a conceptual change. Therefore, the teacher could do is to ensure that students can at least remember the textual content of the concepts. Then, after memorizing the concepts, encouraging students to actively think and understand has become an unavoidable task in and after teaching. What Freddie does is to add corresponding exercises.

T: ...Let's use the left-hand rule to verify whether the experiment we just did meets the relationship in the left-hand rule. We choose the second group, how should we place our hands? The magnetic line of the induction line enter into the palm, and the direction of the four fingers indicates the direction of the current, the direction of the current. The current flows vertically in, and the direction of the thumb is the direction of the Ampère force. right? This is the left-hand rule, the rule for judging the direction of the Ampère force. According to the left-hand rule, let's look at the

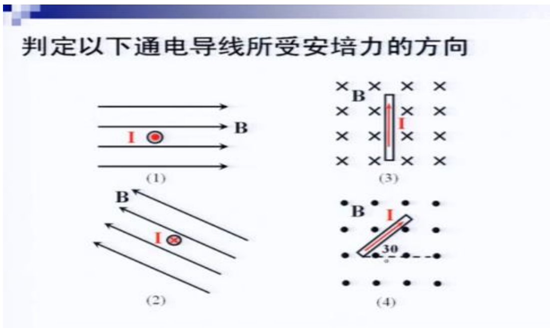


Figure 5.7 Freddie's slide of class exercise

following exercises. Chen, come up and demonstrate the first question, the first question. Let's see if she does it right.

Chen: The current flows out perpendicular to the paper surface, the direction of the magnetic field is to the right, and the direction of the Ampère force is upwards.

T: Well, the Ampère force direction is upward. right? Well, show us the second question and demonstrate it...

(Freddie, F5-O)

Freddie still maintains a self-talking style. Freddie demonstrates using the left-hand rule to determine the direction of the Ampère force and does not join any interaction. Freddie sets up classroom exercises, there is no pause and no time for students to think and digest. When the exercise is displayed on the screen, Freddie designates a student (Chen) to explain the exercises. In Freddie's mind, doing exercise questions are the most effective way of teaching (F5-I).

As far as I talk all the time, students may not understand it. They still have to practice and do *the exercises by themselves in order to have a deeper memory and a deeper understanding of this concept. Moreover, what do you think is the aim that students learn upper-secondary school knowledge for? Just to get a good score in Gaokao. Then, how to take Gaokao? Just do the exams, do exercises. So doing exercises is the most efficient. These are all question types that will appear in the exam. Doing the questions can also exercise the children's thinking, understand the concepts, and exercise problem-solving thinking, which can also be beneficial to the exam. It is much more effective than fancy activities. (Freddie, F5-I)*

The Ampère force demonstrator is used as a demonstration experiment, which is the only activity that other than lecture used in Freddie' class. The rest of the content is in the form of exercises and examples to deepen students' understanding. Freddie draws a schematic diagram on the blackboard throughout the class, studies the direction of Ampère force based on the diagram, and introduces the general form of the Ampère force calculation formula. His language is simple and direct, the semantic wave is smooth, and the students' answers are smooth. Freddie is facing his students, who have already learned the concept and physics formula of magnetic induction strength. Therefore, Freddie's lesson does not require too much explanation, and it eliminated the link of hypothesis and conjecture. While Freddie's class is smooth, there are fewer surprises. The entire classroom is almost under Freddie's control, and some of the questions are asked and answered by Freddie, without interacting with the students. Although Freddie’s classroom design does not have many activities, Freddie focuses on the combination of numbers and shape, and uses illustrations and examples to enhance students' understanding. The semantic wave jumps evenly between I-IV.

5.2.2.2 The characteristics of other teachers' semantic waves

This section discusses the other four teachers' teaching discourse and relative semantic waves.

The semantic waves of **Charlie**'s classroom discourse during the whole class is mostly jumping between I-II. When introducing formulas and the left-hand rule, the semantic waves briefly reach III or IV. Charlie changes the discourse according to the students' answers. When students show that they do not understand, Charlie switches the language to everyday language. When the students' answers smoothly, Charlie revises their answers. The whole class is centred on the magnitude and direction of the Ampère force, and the teaching purpose is clear. The class involves formulas, images and other professional content. Charlie explains the formula and images after giving out them. Charlie is well prepared and has teaching experience. During Charlie's teaching, when the students do not respond to questions, Charlie activates the atmosphere of class in time, calms the students' emotions and slows down the teaching process. The students Charlie faces are the same group of students from Jack's in Topic M. The reason why the atmosphere is not active might be that the difference between the two teachers or the topic. Charlie designs fewer student-centred classroom activities and uses teacher-centred activities to fill in the whole lesson. Charlie operates the demonstration experiment and reads the data. Students’ tasks are only to record data, analyse data and give conclusions, which are relatively boring for students. In a few places that need experimental verification, Charlie just concludes discussion and passes by (shown in Example 1). The design of the demonstration experiment lacks consideration, which causes students to hesitate when answering questions related to the experiment.

Example 1

T: ...What factors may be related to the amount of Ampère force? Let's start the discussion

[group discussion]

T: If you know the answer, just speak it out, when the discussion is over. This group, please. Can you share your opinions?

S1: It may be related to the amount of current, and also related to the length of the wire. Em...

T: Is there anything else?

S1: It may be related to its material.

T: Oh, also related to the material.

S1: That's all.

T: Please sit down. Please stand up again, I just want to communicate with you, don't be too nervous, love. It is related to the material, do you mean that it is related to the resistance of this conductor?

S1: En.

T: Well, please answer it, this is a foil tube, will its resistance change before and after power on?

S1: No

T: No, then it will feel the force both when the power switch on and off, and at this time its resistance is constant, then do you think that the amount of Ampère force is related to resistance?

S1: I guess not

T: Ah, ok, please sit down. Are there other groups that have other ideas? That group.

S2: I think it might be related to magnets.

T: That means the magnet's? Give us more details, please

S2: Different magnets may have different forces, on the same energized wires.

T: I add something for you, you just say right or wrong. Do you mean the strength of the magnetic field generated by a magnet?

T: Good

(Charlie, F1-O)

It is caused by the high content intensity of Topic F which requires the students to understand the magnitude and direction of the Ampère force in a short time. It is difficult to complete without learning the magnetic induction intensity. What needs to be explained here is that in the previous analysis of the textbook, it is mentioned that the order of the textbook is that the teaching of magnetic induction intensity is before this class and should belong to the prior knowledge of this class. Due to the recording of the show class, the students are taught Ampère force after studying the magnetic field. This is caused by the arrangement of the show class activities which does not take into account the students' prior knowledge.

Ava's voice is very friendly. She walks to the students to ask questions, and she leans down when talking to the sitting students. The professionalism of Ava language is similar to Oliver in Topic M, their waves are large fluctuations. The difference is that Ava’s use of life-oriented language plays an active role, not in the explanation of physics concepts. Ava uses a joke to correct students' mistakes or attract students' attention. The feedback is given by the students seems more relaxed and active.

T: ...Then this model can help us judge the direction of Ampère force. Is it easy to use? Then, put it back in your bag, why not?

S: It is too big, too long.

T: It’s too long to fit and it’s inconvenient to carry, right? Can you find an item that can be used to determine the direction of Ampère force and can be easily carried to replace this model?

S: We can use our left hand instead.

(Ava, F2-O)

Ava and Charlie have different orders in the arrangement of courses. Firstly, Ava explores the direction of the Ampère force and then studies the magnitude of the Ampère force. This arrangement is more conducive to the acceptance of students, as can be seen from the responses of students. The direction is obvious from the experiment, easy to operate, and easy to conclude. In the first 30 minutes, the semantic waves fluctuate between I-II. After that, in exploring the magnitude of the Ampère force, it is necessary to make assumptions about the influencing factors, observe the readings, and make the graphs, and finally get the calculation formula of Ampère force. Direction first and then magnitude is a process of gradually advancing from shallow to deep, which is more in line with students' cognitive laws. Therefore, in the last 10 minutes, the semantic waves reach III or IV many times.

George and Ava are the same, introduce the direction of Ampère force first, from shallow to deep knowledge. George's semantic waves generally have the same trend as Ava's (shown in Figure 5.8). The self-made speaker is used as an introduction to arouse students' interest and invest in the study of this lesson. At the end of the class, the self-made speaker is used to apply the knowledge just learned, which echoes back and forth and is conducive to the consolidation of student knowledge. Topic 2 involves the formula of Ampère force. George disassembles the formula and explains it one by one. George also explains the physics symbols accordingly. Therefore, the image of the semantic waves has multiple crests. In George's class, there are many languages and activity gaps, which means that George does not speak or arrange student activities during this period (shown in Figure 5.8). George brings a large number of experiment equipment which could not be fit on the desk and needs to be replaced. This process consumes some time. Especially when the experimental equipment is changed for the first time, it takes two minutes to find the power supply of the experimental device. George's remedy is to let the students read textbooks and do self-study. This phenomenon shows that George is not sufficiently prepared for the experimental demonstration equipment before class. But overall, the few minutes consumed does not affect George's progress in class content, and he still completes the teaching plan on time.

Like Charlie, **Oscar** puts the Ampère force first, the props Oscar prepares as the introduction activity are not properly adjusted. It takes time and the students become a little impetuous after they calm down. After Oscar knows that the time is wasted, he starts to speed up his speech significantly, omits the transition link in teaching, and directly entering the inquiry of the Ampère force. The student's reaction seems a little confused. Oscar's teaching design process involves demonstration experiments, group experiments, and classroom activities, but the speech speed is a little faster. When students doing group experiments, Oscar does not answer questions for students. Instead, he directly instructs students to connect circuits. And constantly urge students to speed up. At the end of the group experiment, the drawing drawn by a student is directly taken away from the student without asking. When analysing the direction of the Ampère force, a student is asked to draw the experimental phenomenon on the blackboard, Oscar does not explain how to draw in advance. As a result, during the demonstration experiment, Oscar discovers that the student does not draw the picture according to his vision. He goes up and down the stage to instruct the student how to draw. The students sit in their seats are laughing. Finally, when the bell rings, Oscar ends the course in a hurry. Oscar has some content not finished (compare to his teaching plan, section 4.4.2). The solution is to leave the following content as homework. These series of behaviours and language show that Oscar has problems with time control and management.

5.2.2.3 The characteristics of semantic waves in topic F

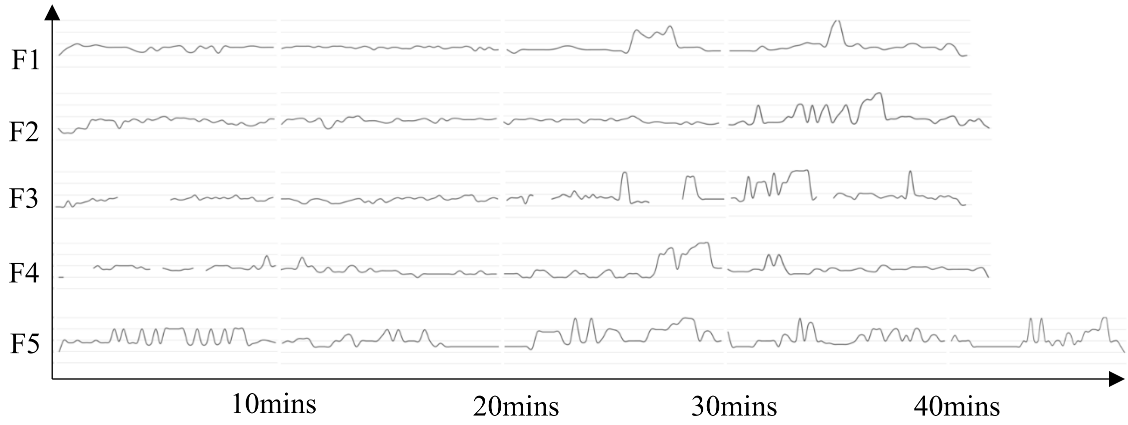


Figure 5.8 The comparison figure of semantic waves in Topic F

In sum, in addition to Freddie, the other four teachers all arrange demonstration experiments, group experiments and classroom activities. During classroom activities, the semantic waves of the teacher's words are mostly concentrated between I-II. In other words, most of them are lecturing, without the corresponding diagrams. Freddie replaces activities with several exercises. The prior knowledge of the students in Freddie's class is different from the other four teachers'. As mentioned earlier, the students face by the first four teachers have not learned the concept and formula of magnetic induction intensity, so this lesson is designed as an inquiry course and a lot of inquiry activities are introduced. Freddie is based on that the students had already learnt the magnetic induction intensity. As a semi-review course, after deriving the Ampère force formula from the magnetic induction intensity formula, Freddie uses exercises to deepen students' understanding. The overall amplitude of the semantic wave of Topic F is larger than that of Topic M, because Topic F involves the schematic diagram of the direction and the Ampère force formula. George and Ava are similar in form of semantic waves. They arrange the explanation of the direction of the Ampère force first and then explore the magnitude of the Ampère force. The exploration process is described in professional language, and finally, the formula of Ampère force is obtained. Therefore, the semantic wave fluctuates between I-II in about 30 minutes. The semantic wave reaches III or IV in the last 10 minutes (Figure 5.8). George realizes that some time is wasted in preparing the experimental equipment. During lecturing, George drives the time forward a bit, and it can be seen that the semantic wave crest has moved forward. George and

Freddie split the formulas and explain them in turn. There are several crests in the semantic wave (Figure 5.8). Freddie uses the schematic diagram to facilitate his explanation. Thus, there will be many several small peaks and gently rising images. Oscar's semantic waves are fragmented, and there are meaningless blanks during his teaching (Figure 5.8). Furthermore, the sequence of knowledge points of Oscar's and Charlie's classes are the same, therefore, the general trend of semantic waves is similar. As Oscar realizes that group experiments and discussions take too long, he accelerates the pace of lectures and shortens the time required for the Ampère force magnitude. It can be seen from the semantic wave image that the waveform trends of Oscar's and Charlie's are the same, except that the peak groups with amplitudes of IV and III are closed.

5.2.3 *Topic E: electric field strength*

The semantic waves in Topic M have small fluctuations, and it is not easy to conclude that semantic waves are synchronized among different teachers. At the beginning and end of the lesson, the semantic waves are at the trough positions. Through the analysis of Topic F (6.3.2), the five teachers are mainly lecturing. Although there are differences in the setting of teaching activities, the overall trend of semantic waves is similar. The crests appear at a similar time point. The same part among teachers can be seen as the semantic wave characteristics brought by the topic. The difference lies in the teacher's teaching design, style and instant performance.

Topic E is different from the previous two topics in that it is the content of the first chapter of this textbook, and it is the first concept that students have contact with the field and have a preliminary quantitative understanding of the field. The 'Electric Field Strength' section of the current textbook is arranged after the content of Coulomb's law. The textbook firstly introduces the concept of the electric field, pointing out that there is an electric field around a charge, and other charges in the electric field are subject to the force exerted by the electric field. The field and the object are two different forms of matter, and the field has momentum and energy. Then, the textbook starts with the electrostatic force to study the electric field. It is concluded from the experiment that the strength of the electric field is related to the position. The focus of research shifts to the study of the strength of the electric field, it is necessary to introduce a probe charge. The amount and volume of the probe charge should be sufficiently small to guarantee the original electric field is not affected. Studies found that the electrostatic force of the probe charge at different positions is generally different. The electrostatic force exerts on the probe charge cannot be used directly to express the strength of the electric field. The reason is that the probe charge with different amounts of charge receives different static forces at the same point. Therefore, the textbook proposes a hypothesis based on the conjecture that the force, F, received by the probe charge at a certain point in the electric field is likely to be proportional to the amount of probe charge q, that is, F=Eq. Experiments show that at the same position of the electric field, the proportional constant E is constant. At different positions of the electric field, the proportional constant E is different. E is unrelated to the probe charge q. It reflects the nature of the electric field and is called the electric field strength, and its expression is E=F/q. It is precise because of the characteristics of this class that most of the teachers involved in this study are mainly lectures, guiding students to understand the concept of the field and to study the characteristics and strength of the electric field during the lesson. Although the teaching strategies are similar, the teacher's languages are different.

5.2.3.1 Ella's teaching process

After the greeting, Ella introduces an instructional tool – a plasma ball – as a means of class initiation. The plasma ball is a commonly encountered object in everyday life, often depicted as beautiful and magical in casual discourse. Within the physics classroom, Ella employs the plasma ball as a demonstrative aid to acquaint students with the concept of an electric field. The pedagogical language used encompasses an extensive array of scientific terminology, covering elementary physics principles and concepts. Consequently, there is a semantic wave that hovers around area II.

T: ...Did everyone see it? Have you seen it? What's it called? Forgotten? It's an plasma ball. It's an energy-saving bulb. What will happen when the bulb is near the plasma ball?

SS: Bright.

T: The light indicates that it's receiving electricity. Do you guys know whether energy can just appear out of nowhere or not?

SS: No.

T: Yeah, energy can't be created out of thin air. So the source of this energy must be somewhere.

SS: The plasma ball.

T: Right, it must be the plasma ball, right? Then, this plasma ball, an electrostatic sphere. What does it have?

SS: Electricity.

T: It produces something you can't see or touch.

SS: Energy.

T: And what gives this bulb energy and makes it glow?

SS: Electricity.

T: What is it? Today we're going to learn about the electric field. Good job!

(Ella, F4-O)

Following the situational introduction, Ella transitions into the core content of the lesson by commencing with a recapitulation of previously covered material from prior classes, which delves into the interrelationships among various physics quantities. Ella guides the students step by step through language to arrive at the correct relationship between physics quantities, the calculation formula. As such, the semantic wave of instructional language rises around area IV.

T: The interaction between charges, people had spent a long process of understanding in the history of physics, so let's review what we learned last time about Coulomb's law, take it easy, think about it.

S: The interaction between two point charges in a vacuum.

T: With what? Be proportional to?

S: It's directly proportional to their charge.

T: It is proportional to charge's what?

SS: The product.

S: It's proportional to the product of their charge and inversely proportional to the square of their distance.

T: Very good. Sit down, please….

(Ella, F4-O)

In Chinese physics classrooms, it is a common practice for the teacher to instruct students to engage in pre-class preparation by reading the textbook and completing workbook exercises before delving into the main content. This serves to facilitate a smoother flow of subsequent lesson. During this brief period, which lasts approximately one minute, students are observed quietly engrossed in their textbooks and workbooks while the teacher circulates around the classroom, creating an atmosphere reminiscent of students taking an exam under supervision.

T: … Please read page 10 of the textbook and complete the corresponding tasks on the study guide.

[Students are reading while teacher is walking around]

T: OK. …

(Ella, F4-O)

'*The current content in the textbooks is easily comprehensible, and my aim is for kids to* *develop a conceptual understanding of today's topic through guided self-study, thereby facilitating smoother teaching and deepening students' knowledge*.' (Ella, E4-I) Ella endeavours to assist students in retaining the language of physics expression using this method, enabling them to swiftly engage with the discourse system of physics and ensuring that teaching flows seamlessly with instructional language present in area II. Nevertheless, there remains uncertainty regarding whether this approach genuinely signifies an enhancement in students' comprehension of knowledge. This concept bears resemblance to Freddie's strategy in Topic F, which centres on the belief that students must first commit corresponding concepts to memory before grasping and internalizing physics quantities.

The worksheet is designed based on the textbook, and students respond in accordance with the textbook. This process is expected to proceed smoothly, akin to Ella's 'exemplary' classroom performance, where teachers and students effortlessly exchange answers. However, it appears that merely completing fill-in-the-blank exercises aligned with the text should not constitute the primary objective of a science course.

T: Okay, you, please. Please give the answer to the question on the screen.

S: There is an electric field around a charged particle, and other charges in the field experience a force that is given by the electric field.

T: Good. Can you explain this picture using the words you just used? Around who ? Around who, A or B?

S: A.

T: Around A, there is what?

S: An electric field.

T: There is electric field generated by who?

S: A.

T: An electric field is generated by A and then?

S: It has a force on the B charge.

T: It exerts a force on the B. Where is the charge? It exerts a force on charge B in where?

S: In the electric field.

T: In the electric field. Very good. Sit down, please.

(Ella, F4-O)

When Ella's question involves content that students fail to comprehend, the ideal response becomes elusive and erroneous answers may emerge. These incorrect responses often stem from preconceived notions held by the students. Ella addresses the conflict between the constancy of electric field and the variability of force with respect to charge position, aiding students in recognizing that assessing the strength of an electric field cannot solely rely on force magnitude.

T: This is the diagram we went over last class. Now that we've learned about electric field, we should have a better grasp of this diagram. What do you understand from it? Let's think about a few questions: Why does the string move?

S: It is exerted a force.

T: What kind of force?

S: A repulsion force.

T: Repulsion, who causes it?

S: The electric field produced by O.

T: She said the electric field is caused by O. She answered the second question. Why is the angle of the string different at different positions?

Ss: Because of the distance.

T: Yes, because each position has a different distance. Why are there varying distances and angles, and why does the electric field have strong and weak strength? That's great! How do we measure or describe the strength of an electric field? Can we use this force to describe it? Both the electric field and force have strengths, can we rely solely on force?

Ss: Yes.

T: Then let me ask another question. Look here, if I double the charge at this position, will the force change?

Ss:Yes.

T: By how much?

Ss: It will double too.

T: What does that mean? Is there always an equal amount of force for every charge at any given position？

Ss: No

T: So can we only rely on describing it with just force alone？

Ss: No

T: What else do we need？

Ss: Charge

T: Now, we need a new physics quantity to describe or measure an electric field's strength.

(Ella, F4-O)

After guiding students to recognize that describing electric field strength cannot solely rely on the physics quantity of force, Ella's guidance appeared somewhat ineffective. Despite Ella's attempts to introduce the concept of source charge and test charge through language guidance, students remained fixated on the concept of force and struggled to accurately answer her questions or identify the test charge based on her guidance and information from the textbook. At this juncture, instead of investing more time in guiding them, Ella explicitly mentioned the test charge and continued utilizing a question-and-answer approach to elucidate its characteristics as a physics ideal model. Although there seemed to be interaction during this guided process, students mechanically echoed Ella's words in an attempt to provide satisfactory answers.

T: To depict its strength, we introduce a charge. Why?

Ss: To generate an electric filed .

T: So this charge is electric field, what?

Ss: Its centre.

T : Does it act as source for generating electric field? We call this charge field source or source charge. But having just one doesn't show us anything about an electric field. What else do we need?

Ss: Force.

T: Let's try another charge. The source charge creates an electric field. This is called a test charge, or a probe charge. It's here and it feels a force. What do we need for this test charge?

Ss: A small enough amount of charge.

T: Yeah, a small enough amount of charge, and does it need to be small in size too?

Ss: Yes, small enough.

T: Why? Who mentioned it?

Ss: So that it doesn't have any effect.

S: The test charge shouldn't affect the electric field created by the source charge.

T: What aspect doesn't it affect? A's? Distribution of charges. What is the purpose of making it very small? To do what exactly? To accurately examine the electric field, right? What if it's too big? The picture pixels is too small and not precise. Got it now? Great! Take a seat, let's go over this again. The test charge needs to have a tiny amount of charge so that, what will not be affected?

Ss: Not to affect the electric field.

T: Not to affect A's distribution of charges. So why does its size and volume need to be very small?

Ss: For precision.

T: Exactly! Having an accurate description. Fantastic.

(Ella, F4-O)

Ella introduced the formula for electric field strength and subsequently presented three classroom exercises to facilitate students' comprehension of its application in problem-solving. Additionally, she derived the formula for electric field strength of a point charge in free space. Throughout this process, the semantic wave image intersected with area II, III, and IV, illustrating the waveform resulting from an analysis encompassing images, mathematical relationships, and physics correlations.

5.2.3.2 The characteristics of other teachers' semantic waves

Topic E differs from the preceding two topics in that it constitutes the content of the initial chapter of this textbook, serving as students' first exposure to and comprehension of quantitative aspects within this field. The precision stems from the nature of this course, wherein a majority of instructors primarily deliver lectures aimed at facilitating students' understanding of fundamental concepts and exploring the characteristics and potency of electric fields during instructional sessions. Although teaching strategies may be similar, there exists variation in teachers' linguistic approaches that could be seen from their semantic waves directly. As elucidated in the analysis of their teaching plan (section 4.4.3), topic E's instructional design aligns most closely with the prescribed materials, thereby ensuring consistency among educators.

Similar to Ella, **Ivy** also reviews the previously learned formulas before delving into the main content; within the initial ten minutes, her waveform analysis indicates placement in area IV. Unlike Ella's approach of incorporating physics relationships, mathematical correlations, or graphical analysis assistance when introducing the electric field strength formula, Ivy consistently employs letter representation for physics quantities throughout the entire process, resulting in waveforms with a rectangular shape.

T: … In space, there is a point charge. Then, at two different positions, r1 and r2, there are two points, P1 and P2, respectively. If we place two charges at these two points, the force they experience should be F1 and F2, which can be calculated using Coulomb's law. For example, what should F1 be at the P1 position? Let's say it together. What should it be?

Ss: k times Qq divided by r12

T: Yes, k times Qq divided by r12. What about the force at P2?

Ss: k times Qq divided by r22

T: k times Qq divided by r22, obviously the force is different in size. …

(Ivy, F1-O)

Mia, Emily, Daisy, Hannah, and Luna initiated their classes with introductory activities and a brief overview of relative scientific history. The classroom discourse alternated between area I and II. Due to time constraints, **Mia** and Ella were unable to complete their planned lesson on the superposition of electric field strength and knowledge summarization; instead, they concluded the class by deriving the formula for electric field strength of point charges and engaging in practice exercises. **Emily** compressed the scenario introduction and expedited the main content during teaching by incorporating both the principle of electric field superposition and uniform electric field concepts. Emily's overall classroom discourse exhibited a more consistent semantic wave compared to other teachers, with area IV concentrated in the latter half of the class. **Daisy** dedicated ten minutes in her class to explaining the vectorial nature of electric field strength through practice exercises without involving any formulas; consequently, her classroom discourse semantic wave fluctuated around area II during that period. **Hannah** and **Luna**'s teaching discourse oscillated around area II for less than ten minutes towards the end of their class while explaining analytical practices related to directionality of electric field strength.

5.2.3.3 The characteristics of semantic waves in topic E

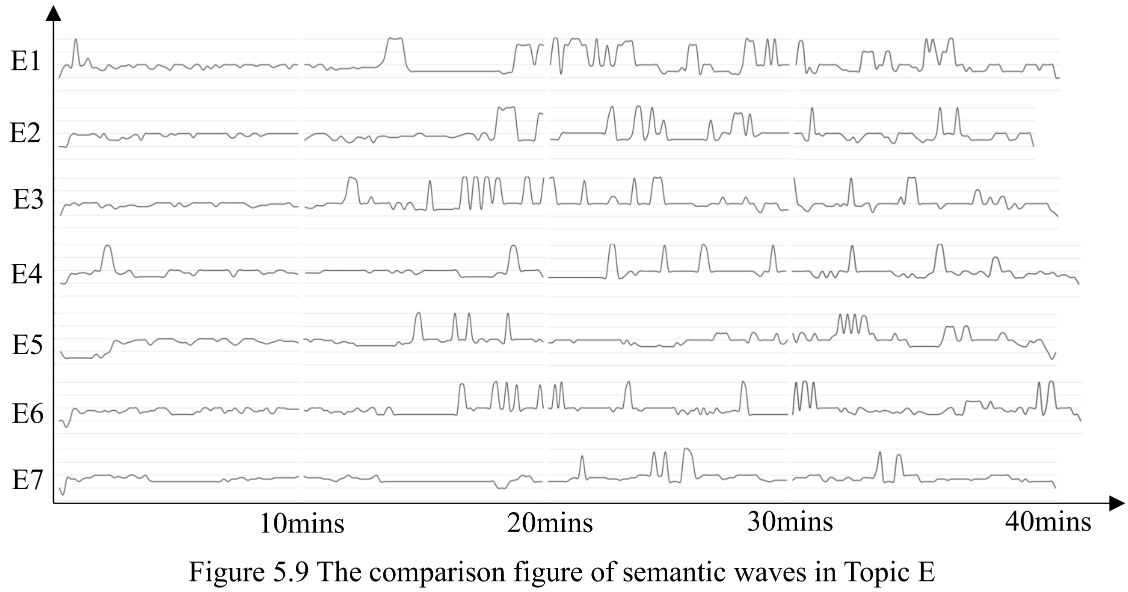


Figure 5.9 The comparison figure of semantic waves in Topic E

The objective of the initial two sections is to amplify the semantic waves, subsequently focusing on the distinct expressions exhibited in each sentence. This section elucidates the issues that can be discerned when teachers employ classroom discourse's semantic waves as a means of self-reflection by comparing them with other extant semantic waves pertaining to the same topic.

From Figure 5.9, the overall trends of the semantic waves of the 7 teachers are similar. They all reflect that the first ten minutes fluctuate between I-II, and the wave that reaches the peak of

IV from the second ten minutes, which continues to the end of the course. It is brought about by the characteristics of Topic E. In the early stage, teachers need to explain and introduce the topic, and then allocate nearly thirty minutes to analyse the formula and the related concepts of electric field strength.

The waveforms that appear in the semantic waves of Topic E classroom discourse are concentrated in the following four categories:

⁕ In the first ten minutes of class, there are small fluctuations between I to II.

All seven teachers have small fluctuations in the first ten minutes of class. Among them, only the classes of Ivy and Ella involves the formula of Coulomb's law or the mathematical relationship between physics quantities. Therefore, the semantic wave of these two classes has a peak of IV at the beginning of the course. The other five teachers review Coulomb's law. They do not expand it further, only mentioning the concept and its definition.

⁕ Flat-line.

The seven semantic waves all appears flat lines of different lengths without fluctuations. These flat lines correspond that teachers let students carry out classroom activities and patrol the classroom. The classroom activities include letting students do exercises (E2-O, E3-O, E4-O, E5-O, E6-O, E7-O), students discussion (E1-O, E5-O) or reading the book to find the corresponding answer (E4-O, E7-O).

⁕ Large fluctuations between I to IV, and there are multiple continuous peak groups.

The semantic wave reaches IV, which is what the teacher involves in analysing the relationship between the physics quantities in the electric field strength formula.

⁕ In the last 30 minutes of class, there are continuous small fluctuations.

In the process of analysing the electric field strength formula, the teachers analyse and explain the classroom exercises.

5.2.4 *Common waveform types and distribution characteristics of the semantic waves*

The purpose of this section is to summarise the language teachers use in their teaching. These seventeen lessons are all carefully prepared by teachers to demonstrate and participate in the appraisal. The language has been carefully considered and re-examined. Based on the collected data analysis, there is a large degree of convergence in language expression. There are the following types of semantic waves:

Small fluctuations between 1 to 2 (the semantic waves shown as Figure 5.10)

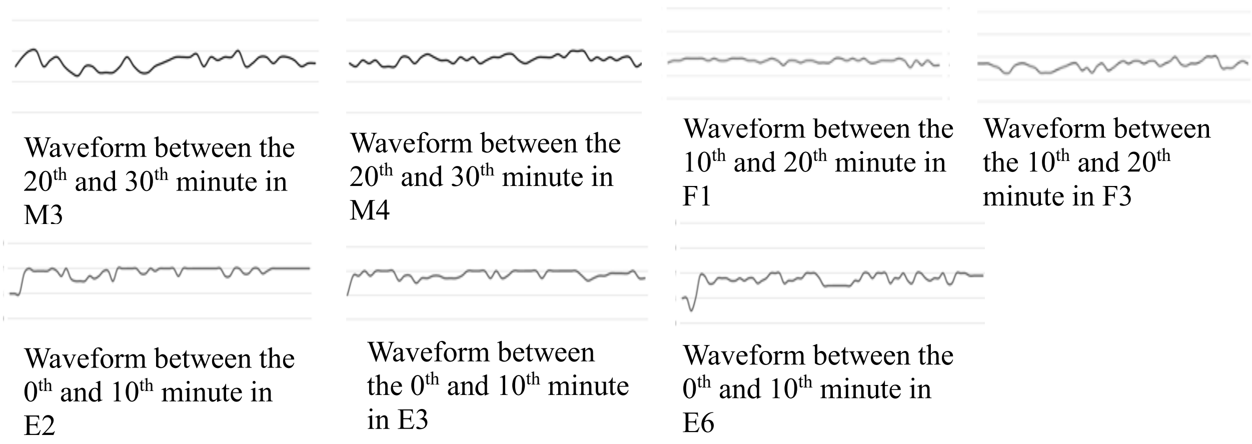


Figure 5.10 The examples of small fluctuations between 1 to 2

Small fluctuations are common in the classroom discourse of each teacher. Small fluctuations, that is, fluctuations between 1-2. The content of the utterance does not involve illustrations and formulas. The semantic wave waveforms of the five teachers in Topic M all shows small fluctuations. This is in line with the teaching content of Topic M. As had mentioned in the previous section, the description of the magnetic field's nature is the basis for learning electromagnetic knowledge in the future (Ke & Ma, 2016; Peng, 2009). This topic introduces the underlying magnetic phenomena, magnetic effects, and geomagnetic fields based on relevant knowledge taught in secondary school (MoE, 2017b; Peng, 2009). The maximum amplitude of the wave is around 2. The semantic wave of Topic One fluctuates between 0-3. According to the changes in the classroom content, the waveform jumps in different intervals. Semantic waves are mostly concentrated around 2 and drop to interval 1 at the beginning and end of the class and other limited-time points. It shows that classroom discourse is focused on the explanation of abstract concepts and laws. The occasional life-like language is used to visualize concepts or conduct classroom management. In the semantic waves of Topic F and Topic E classroom discourse, a considerable part of the waveforms shows small fluctuations. The corresponding teaching behaviour is introduction and classroom activities.

The rise and fall of the semantic waves with small fluctuations are determined, on the one hand, by the distinction between abstract concepts or rules (2) and real-world examples or instructions (1), which involves the classification and formality of the language. On the other hand, it is determined by the framing of the language. In the formality of language, teachers' performances are relatively similar. Except for the introduction of a classroom, an analogy with phenomena in life and classroom management, most of the languages are physics languages with distinct disciplines. In some cases, teachers choose to read the original text in the textbook directly by themselves or ask the students to do it. The language used by teachers in the introduction process is life-oriented and does not have subject specifications, and classification is weak. The semantic wave downs. When teachers teaching about the concepts, specific terminology is involved in each sentence, the classification is strong. The semantic wave rises.

1 *Teacher: Class begins!*

2 *Monitor: Stand up!*

3 *Students: Good morning/afternoon, teacher!*

4 *T: Good morning/afternoon, everyone. Sit down, please.*

(M(1-5)-O, F(1,2,3,4)-O, E(1-5, 7)-O)

Seventeen teachers in this study use the classroom routine of starting a class - Class begins. The language in this classroom management process is not subject to professionalism, and classification is weak. The other two teachers went directly to the introduction part after the students are seated, and do not include the 'class begins' part. This classroom routine is part of teachers' classroom management. It is used to maintain the order of the classroom and give the class a sense of ritual. It contains Chinese cultural characteristics, 'zun shi zhong dao', respect for teachers and 'the way'. The sense of ritual seems to some teachers to make students feel relieved and can be used as a transitional link between break and class. The sense of ritual could be viewed as rules, which are spontaneous rituals and negotiated conventions (Griffin & Mehan, 2011). It is indeed dispensable in the ideas of other teachers. They even feel that this external sense of ritual would hinder students from forming spontaneous self-discipline (F5-I). It is undeniable that this kind of pre-class ceremony is common in Chinese classrooms based on my study and work experience in China for almost thirty years.

In the formality of language, teachers in this study rarely use nominal groups and complicated clauses, instead, uses parataxis sentences and simple sentences. This feature appears in the analysis of Chinese upper-secondary school textbooks (section 4.3.1). The ups and downs of semantic waves based on the nominalisations and syntactic complexity are not found in the classroom discourse of the sample teachers.

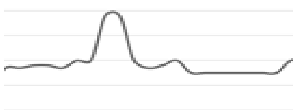
In classroom teaching, the language is referred to as the main statement and the third person, which is a low framing. The semantic waves fall. A large number of second person and imperative sentences are used in classroom activities and Q&A sessions, and the framing here is strong. The semantic waves rise. Although teachers use interrogative sentences instead of imperative sentences as much as possible, teachers give little or even no time to think after the question, which reveals that the teachers are expressing commands or informing. Many of the questions are in the form of

Yes/No, such as '..., right? ', '..., understand? ' and '..., are they?'. It is not a question, but a request for a response from the student. The semantic waves rise in such situations.

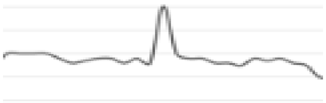
Large fluctuations between 1 to 4 (the semantic waves shown as Figure 5.11, Figure 5.12, and Figure 5.13)

Large fluctuations only appear in Topic F and E. The semantic wave reaches 4, which indicated that the teacher involves in analysing the relationship between the physics quantities. The semantic wave reaches 3, which shows that the teacher explains in combination with diagrams. There are three manifestations of large fluctuations

⁕ Single peak



Waveform between the 0th and 4th minute in E4



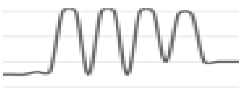
Waveform between the 35th and 40th minute in F3

Waveform between the 31th and 38th minute in F1

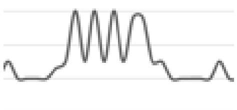
Figure 5.11 The examples of single peak

A single crest signifies the absence of any other significant wave crests occurring within a five-minute interval before or after the crest. The teacher or student describes the experiment process and conducts experiments, describes the relationship between physical quantities (single peak), and then further introduces the prerequisites and the meaning of each letter (F1-O, F3-O). Alternatively, at the commencement of the lesson, the teacher revisits the content learned in the previous lessons, solely addressing interrelated formulas or physical quantities (E1-O, E4-O).

⁕ Crest group



Waveform between the 15th and 19th minute in E3



Waveform between the 31th and 34th minute in E5

Waveform between the 32th and 35th minute in F2

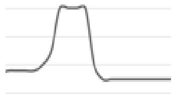
Figure 5.12 The examples of crest group

The waveforms that appear concentrated with large amplitude peaks are the crest groups. When the teacher is disassembling the formula, introducing the relationship between the physical quantities, interspersing with students in the middle, introducing the prerequisites or operating the experimental equipment, the crest group appears.

⁕ Trapezoidal wave

Waveform between the 25^{th} and 30^{th} minute in F1

Waveform between the 25^{th} and 30^{th} minute in F4



Waveform between the 13^{th} and 16^{th} minute in E1

Figure 5.13 The examples of trapezoidal wave

Trapezoidal wave refers to the existence of a continuous wave with a large amplitude, which is shaped like a trapezoid. The teacher concentrates on introducing the mathematical relationships between diagrams, formulas or physical quantities, without inserting explanations and analyses (F1-O, F3-O, F4-O, F5-O, E1-O and E2-O).

The wave crest group is like a disassembled trapezoidal wave, and the trapezoidal wave is like a superimposed wave crest group. The wave crest group is the language of explanation and interaction between the crests, which is used to dilute the difficulty of understanding the mathematical relationship of physical quantities. The trapezoid wave is more like a concluding discourse after experimental analysis or logical reasoning (F1-O, F3-O, F4-O, F5-O). Otherwise, Ivy and Mia choose to first give out the mathematical relationship between formulas and physical quantities and then use exercises to further explain and analyse the relationships and points that need attention (E1-O and E2-O). If the distance between the sampling points increases, the crest group will also become a trapezoidal wave.

Flat-line (the semantic waves shown as Figure 5.14) and blank space

Waveform between the 17^{th} and 18^{th} minute in F5

Waveform between the 0^{th} and 2^{th} minute in M4

Figure 5.14 The examples of Flat-line

The flat-lines are the semantic waves that are without any fluctuation. Some flat lines correspond that teachers let students carry out classroom activities and patrol the classroom. The classroom activities include letting students do exercises (F5-O, E2-O, E3-O, E4-O, E5-O, E6-O, E7-O), students group experiment or discussion (M3-O, M4-O, F3-O, F4-O, E1-O, E5-O) or reading the book to find the corresponding answer (E4-O, E7-O). The teachers do not have any words during the inspection, or the semantic waves of discourse do not fluctuate. Other flat lines indicated that teachers are lecturing (M2-O. M5-O, M4-O, F1-O, F2-O), describing the experiment phenomena (M1-O, M2-O, M3-O, F1-O, F2-O, F4-O), reading data (F3-O) or doing an introductive activity (M4-O). Overall, the percentage of time that the flat-lines appear in each class is low. The position of the flat line is relatively irregular. The amplitudes of the flat lines are all-around 2, indicating that the discourse is introducing concepts or laws.

There are gaps in the semantic waves in some lessons (F3-O, F4-O). During the blank space time, the teacher has not arranged any classroom activities, and there is no language explanation. The class is silent. Teacher Oscar and George think this is a teaching accident because the teacher is not fully prepared (F3-I, F4-I). Teacher Jack, Ava and Leo think this is a time for students to relax (M1-I, F2-I, M4-I). In forty minutes, students cannot always be in a tense phase. The teacher could leave a blank for the classroom, and time for students to free their brains. Furthermore, some researchers believe that the blank should be 'scientific' (Cheng & Li, 2021; Zou, 2020). In other words, there need to be designed blanks in the classroom, not helpless blank space. Teachers leave blanks after creating the situation to let students understanding the process of knowledge formation, awake the individual cognitive structure of students and make students have a deeper understanding of knowledge (Zou, 2020). The 'scientific' blank space is more like the performance of the flat line, indicating the silence after the teacher arranges the classroom activities or the few seconds of thinking time that the teacher leaves for the students after the teacher asks the question.

The flat lines and the blanks show the silence of the classroom, the difference is that the quiet time is reserved by the teacher or generated in the classroom. The flat lines show a ‘preaching’ with a single tone and scientific language.

After conducting an analysis of the common waveform, I attempted to overlay all semantic waves and calculate their average smooth curve assignments within the same time period in order to simulate a common curve representing the holistic classroom discourse. As depicted in the Figure 5.15, it is evident that all examined samples of Chinese upper-secondary school physics classroom teaching exhibit a unimodal curve semantic waveform.

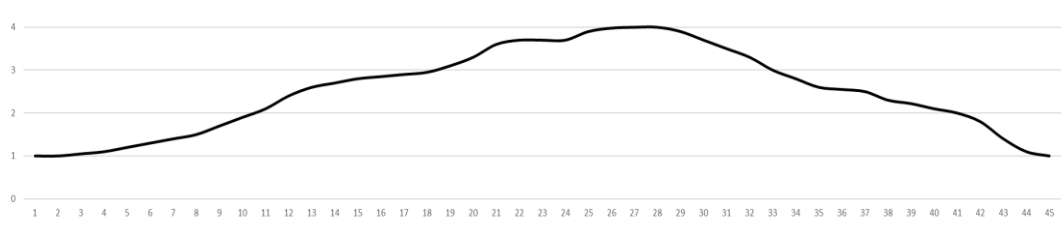


Figure 5.15 45-minute physics classroom discourse semantic wave trend graph

This study presents a semantic wave identification framework, integrating Halliday and Martin’s (1993) notion of formality, Bernstein’s (2003a) framing theory and Maton’s (2013) semantic plane. By analysing the classroom discourse of 17 Chinese upper-secondary school physics teachers, this study fits a unimodal curve. Interestingly, this finding deviate from the U-shaped semantic wave proposed by Maton's semantic wave model framework; however, they are conceptually consistent. The underlying principles remain harmonious. Maton's U-shaped semantic wave elucidates the process of knowledge accumulation, commencing with complex concepts (difficult words) being unpacked and broken down into digestible content for students to comprehend easily. Subsequently, these concepts are consolidated to facilitate the construction of related ideas within students' minds. Conversely, the unimodal curve wave pattern observed in my research explicates Chinese upper-secondary physics teachers' classroom teaching process, which initiates with scene creation aimed at aiding student comprehension of the prescribed instructional objectives and subsequently introducing physics concepts. These physics concepts are then applied to real-life scenarios. Consequently, a rising-then-falling waveform pattern is manifested accordingly.

5.2.5 *Summary*

Classroom semantic waves exhibit four basic waveforms: small fluctuations, large fluctuations, flat lines and blanks. Classroom semantic waves of the same topic show similar trends. Topic M does not involve formula explanation. Its classroom semantic waves are mainly small-amplitude waveforms, interspersed with flat-line waveforms. Topic F, E involve four basic waveforms. In general, large fluctuation waveforms appear after small fluctuation waves, which is the latter part of the lesson. On the whole, the semantic waves of physics classroom teaching are unimodal curve (shown in Figure 5.15).

The semantic waves of classroom discourse among different teachers addressing the same topic exhibit slight variations, primarily attributed to teachers' pedagogical adaptations.

The next section analyses teachers' pedagogical adaptations in detail.

5.3 The semantic context of classroom discourse

This section establishes the semantic context of the classroom discourse in the selected 17 lessons (Appendix 4 shows initial coding of the 17 lessons). Analysis of the initial coding of these 17 lessons indicates three aspects discussed in the theoretical framework (section 2.5). Combined with documents and interviews analysis in Chapter 4, a descriptive analysis is presented in the following three sections to illustrate how teachers construct meaning. This descriptive analysis uncovers evidence-based insights into teaching content, students' knowledge, and pedagogical knowledge.

5.3.1 *Teaching content*

Table 5.2 The scientific methods and concepts involved in the specific topic

Topic	Scientific concepts	Scientific methods
M	Magnetism (M1, M3, M4, M5)** Magnetic induction line (M1, M2, M5) Magnetic field (M1, M2, M3, M4, M5) Magnetic effect of current (M1, M3, M4, M5) Ampère's law (M1, M5) Geomagnetic field (M4, M5) Development history of magnetism in Ancient China (M3, M4)	Hypothesis (M1) Experiment (M1, M2*, M3, M4*) Observation (M1*, M2, M3*, M4*) Analogy (M3, M4, M5)
F	Ampère force (Application) (F1, F2, F3, F4, F5) Left-hand rule (Application) (F1, F2, F3, F4, F5)	Experiment (F1, F2, F3*, F4, F5) Observation (F2*, F3*, F4*, F5*) Analogy (F2, F4) Control variable (F1, F2, F3, F4)
E	Electric field (Knowledge) (E1, E2, E3, E4, E5, E6, E7) Electric field strength (Comprehension) (E1, E2, E3, E4, E5, E6, E7) Electric field line (Application) (E3) Uniform electric field (E3) Superposition principle of the electric field (E1, E5, E6)	Ratio definition method (E1, E2, E3, E4, E6, E7) Idealised model method (E1, E2) Analogy (E5) Experiment (E1*, E2, E3*, E4*, E5*, E6*, E7*) Observation (E1*, E2*, E3*, E4*, E5*, E6*, E7*) Infinitesimal method (E6) Control variable (E7)

**M1 refers to Jack's lesson in topic M

* Implicit scientific methods, these scientific methods have not been pointed out, but they are reflected in the teaching process.

The teacher does not determine the teaching content. However, the teacher's understanding and presentation of content knowledge has an impact on the teaching. The teaching content includes subject knowledge and subject-specific scientific methods and reasoning. The scientific concepts and methods referred to in the teaching of the three topics involved in this study are shown in Table 5.2.

5.3.1.1 Knowledge structure and requirements

Students must understand the physics content, establish physics thinking, and teaching should cultivate their learning abilities. Teachers need to have a clear and profound understanding and grasp of the subject nature of the content. In the process of classroom teaching, teachers should be sensitively discovered and grasp the opportunities that can penetrate the essence of the content.

Topic M:

The teachers design the teaching based on the textbook and curriculum standards. The magnetic field is the main concept in topic one, and the teachers have been teaching around this concept. For other concepts, laws and applications involved in the textbook, teachers add or delete them based on their understanding. Because the concept of magnetic field lines is introduced in lower-secondary school (M3-I), and the concept is more visualized and easy to understand, it can give students space for self-study (M4-I), magnetic field lines are not included in the lesson (M3-O, M4-O).

When Oliver explains the distribution of the magnetic field, he compares the similarity between the bar magnet and the magnetic field around the energised solenoid. Then, he asks whether there is a certain connection between electricity and magnetism, or if they are the same. Oliver uses these questions to penetrate the content of electromagnetics so that the seed of electromagnetics is buried in the students' minds.

The five Topic M teachers review basic knowledge about magnetism learned in lower-secondary school, and start by teaching the interaction between magnets and current (teaching plan shown in Table 4.8 and Table 4.9, while video code scheme shown in Appendix 4). These are

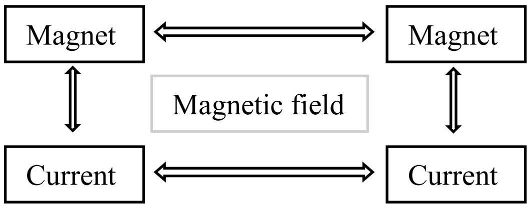


Figure 5.16 The role of the magnetic field

referred to as ‘prior knowledge’ and appear as background in the form of teacher lecturing and students taking notes or question and answer. The distribution and direction determination of the magnetic field is the core content of the five teachers' classes. The magnetic induction line as the imaginary curve describing the distribution of the magnetic field appears in demonstration experiments, pictures and explanations in the classrooms of Jack, Lily and Oliver. The magnetic phenomena in life and the application of magnetic phenomena are the ending part of emotional education, the purpose of which is to make students love science, physics, and China.

These five teachers present knowledge in different ways. Jack, Lily, Sophia and Leo try their best to use well-designed demonstration experiments and group experiments to connect the knowledge. Topic M is an introduction lesson, compared with Topic F and E with more computational content, the teaching content is less, leaving more time for students to observe phenomena and carry out experiments while recalling and consolidating the definitions and laws of magnetism. When Sophia gives a final summary, she compiled the learned knowledge into a poem, which makes the content concise and easy to remember. Oliver's class is all lectured, with some similes containing physics errors in the explanation. For example, when describing interaction of magnets, Oliver gives a simile that the interaction between the magnets like a ‘blind date’, saying that the magnets are men and women on a blind date, and the magnetic field is a matchmaker. Such a metaphor can give students the thought that the magnetic field and the magnet are separate substances, so miss the connection between the magnet and the magnetic field. Oliver compared magnetic field with electric field, effectively linking it to previously learnt material and highlighting the interplay between electromagnetics. This approach lays a solid foundation for future studies in electromagnetics, thereby facilitating the establishment of a comprehensive physics knowledge structure for students.

All the other four teachers except Lily fully presented all the knowledge they designed in advance in the lesson plans (reported in section 4.4.1). In class, Lily gave students time to do group experiments, experience the process of exploration and discovery (around 25 minutes), and temporarily remove the explanation of the geomagnetic field and magnetic phenomena in life from this lesson.

Topic F:

The five teachers teach the concepts and theorems in the textbooks (discussed in section 4.3), adding related physics phenomena and applications. Charlie, Ava, George and Oscar adjusted the order of knowledge. Given that students have not yet acquired knowledge of magnetic induction intensity, it is imperative for teachers to incorporate comprehensive explanations into the lesson, treating magnetic induction intensity as a novel concept introduced to students (section 4.4 and 4.5). The equation and magnitude of Ampère force is new knowledge that teachers delivered, exploring the factors that affect it through corresponding experiments and questions. This adjustment is not made by teachers on their initiative, is a limitation of the conditions of the open class (discussed in section 4.5). It increases the amount of knowledge in this lesson and the difficulty of students' understanding (discussed in section 4.5). Freddie introduced magnetic flux density in the previous lesson to his students. The definition and equation of Ampère force become the prior knowledge of Freddie's lesson, as recommended in the teacher's book. Freddie's lesson focuses on determining the direction of Ampère force and the derivation process of the equation. There is time to practice applying the left-hand rule and deriving the expression of Ampère force at any angle between B and I.

Topic E:

Seven teachers taught from the textbook (CUT). The teacher's book indicates that the content of this section needs two class hours to complete, which requires the teacher to split the content into two. Luna includes electric field, electric field strength, in the first class. Luna believes that students must learn the foundation first, and then proceed to the next step of learning (section 4.5). Emily puts all the content shown in textbook in this section into one class. Emily believes that the content of this section is a complete knowledge system that needs to be presented to students at one time, which is conducive to establishing students' knowledge structure (section 4.5). For example, the concepts, electric field line and uniform electric field, illustrate the invisible electric field visualization which would give students an overall, concrete understanding (section 4.5). Ivy, Daisy and Hannah further introduce the superposition principle of the electric field based on the introduction of the electric field around a point charge. The superposition of the electric field is an important part of the examination (section 4.5) mentioned in the first class about electric field strength. Ivy, Daisy and Hannah stated that the topic will be reviewed in the next class to deepen students' understanding (section 4.5). Mia and Ella believe that superposition of electric fields is an important test point (section 4.5). It was originally designed to be introduced in this class, but time limitations, prevented this (section 4.5). Ella believes that basic concepts need to be consolidated to learn the next step, so it takes a little longer (section 4.5).

Above all, the teacher's choice of concepts follows the teaching material. Teachers' selection of concepts and adjustment of sequence are based on their understanding of knowledge. Some focus on the integrity of knowledge, Ivy, Daisy, Hannah, Mia and Ella consider the importance of knowledge in the examination, and Emily focuses on establishing students' knowledge structure.

The teacher's choice of physics phenomena and physics applications match the demonstration and group experiment design and examples. These activities increase interactivity and interest of the classroom, and assist students in understanding and remembering the main concepts (section 4.5).

Based on the aforementioned analysis, the majority of physics knowledge incorporated by educators in their instructional practices adheres to the prescribed teaching design and textbook. The temporary modifications made by teachers are solely driven by time constraints, taking into account students' prompt responsiveness for additional explanation and experimentation periods.

5.3.1.2 Scientific methods and reasoning

In **Topic M**, Jack, Lily and Sophia make the scientific method explicit. Jack repeatedly emphasises that study physics should first have a guess, make hypotheses and then design experiments to verify them. Jack's teaching process involves raising questions, introducing equipment, designing experiments, describing phenomena, and generalizing rules. Lily does not deliberately emphasize the scientific methods of experiment and hypothesis, however, she emphasises that physics knowledge starts from the phenomena in daily life and requires students to pay attention to the things around them. When talking about magnetic field lines, Lily points out that some physics concepts use concrete objects to describe abstract things. Lily points out that learning physics requires establishing such a mode of thinking. Sophia, Leo and Oliver all set up an analogy between the concepts of magnetic and electric field to help students understand and remember. Sophia, Leo and Lily do not emphasise the physics method of experiment and hypothesis, they used experiments to verify and demonstrate after raising questions in the teaching.

In **Topic F**, Charlie, Ava, Oscar and Freddie identify the experimental method. Nonetheless, observation method is implicit in the experimental method and examples, yet no teacher separately proposed this. Charlie, Ava, Oscar and George emphasise the control variable method, which is not a scientific method specific to physics, and is a mathematical-statistical method. Mathematics is a tool of physics: ‘if you can learn mathematics well, you can learn physics well’ (Oscar responded in the interview). The controlled variable method is a test point, that students need to know (Charlie and Oscar). Mentioning the control variable method is in line with the classroom teaching evaluation criteria and makes the lesson look more brilliant (George). The analogy method appears here to enable students to better understand the concept (George) and effectively connect it with existing knowledge (Charlie). (section 4.5)

Teachers in **Topic E** did not propose experimental methods and observation methods, but integrated them into teaching activities. The methods mentioned to students by the teachers, such as ratio definition (seven teachers), the controlled variable (Luna) and infinite (Hannah), are based on mathematical statistics. The test charge is an important concept in this section. This concept itself involves the idealised model method, which Ivy and Mia mention during the lecture. The electric field strength is one of the core contents of the electrostatic field, and the other is electric potential. The ratio definition method is applied to introduce electric potential (Peng, 2009). Therefore, ratio definition is like a bridge, connecting related electrostatic field concepts. The teacher's book emphasises that attention should be paid to the close connection between electromagnetics and mechanics, and to guide students to form a relatively close ‘knowledge chain’ system (Peng, 2009). The relationship between physics quantities becomes the connection within the knowledge chain. Therefore, when designing lessons and explaining, teachers emphasise the mathematical relationship between physics quantities and use mathematical methods to deepen students' memory.

Mathematical techniques are emphasised separately, which shows importance for their teaching. Most teachers do not reflect physics methods and reasoning explicitly in teaching.

5.3.2 *Knowledge of students*

In the dimension of students' learning characteristic, two points, the teacher's grasp of the students' existing knowledge and pre-concepts, and the teachers' handling of the difficulties and errors that students show in the classroom are significant. Teachers should fully consider and use students’ existing knowledge in designing teaching. Students’ difficulties and errors test the teacher's ability in the classroom and illustrates students’ level of understanding. In the classroom learning process, teachers should respond to problems that students show at any time, thus guaranteeing students' learning new content smoothly.

Based on students' existing knowledge and pre-concepts, teachers design relevant teaching activities, analysed in the previous chapter (Section 4.4). Teachers use relevant knowledge that students have learned to help learning and understanding of new content. There are differences among teachers in their dealings with students' difficulties and errors.

Topic M:

In lower-secondary school, students learned definitions of magnetic field, poles, induction lines, field of the Earth and the magnetic effect of electric current. All were able to talk about the definition and application of magnetism. Episodes based on instructional strategies illustrate that Jack, Lily, Leo and Sophia see this lesson as an introduction course. Most content is reviewing via recalling what was learned in lower-secondary school, making hypotheses based on questions, observing experiments, describing phenomena, and summarising conclusions. The learning strategy of students is low. Oliver incorporated lectures and exercises focused on the determination of magnetic field direction, current flow, and movement. This approach extends beyond mere observation of phenomena and comprehension of laws, as it necessitates students' ability to comprehend and apply these learned principles. Oliver has high requirements for students' learning in this class.

S: I can hold the wire with my hand and made it several times.

T: This is the idea of infinitesimal, but back to the beginning, the middle is straight, which is not easy to explain with this idea. Please think again.

(Jack, M1-O)

Most Q&As in **Jack**'s class are smooth which indicates that Jack has fully considered students' existing knowledge and understanding when designing questions. Jack affirms students' thoughts and points out that his explanation could not explain the phenomena completely, leading the students to think further.

T: ... What can we do to study the distribution of the magnetic field around it? Can you say something about it?

S: Use iron filings.

T: Studied with iron filings, right? Okay, so we're going to use iron filings to explore. Here are iron filings, and we're going to put some iron filings around it. <u>Eh, actually ah, I originally wanted to use this to do the experiment</u>, <u>what is this? A magnetic needle</u>. Which do you think is better? Iron filings, or the magnetic needle? Does anyone agree with my point of view? Is there *any opinions? Well, then, why do you choose iron filings?*

S: The iron filings can reflect the distribution of the magnetic field, while the magnetic needle cannot.

T: The magnetic needle cannot, iron filings can be used to study a region's magnetic field distribution, right? Well, what do you think, it's okay.

S: I think compared with iron filings, the small magnetic needle can only study a point of the field, and can only study the direction, the distribution of magnetic field cannot be studied, density, size also cannot be studied.

T: very good, sit down please.

(Jack, M1-O)

While asking the question about the best method to explore the distribution of the magnetic field, Jack's default answer is the magnetic needle and iron filings, yet the students directly say iron filings. Jack inserts the content of the magnetic needle after the Q&A to complete the pre-set teaching process, even though it might be not necessary. This appears to be an intentional and superfluous action, it would be advantageous to introduce magnetic needle when exploring the direction of the magnetic field later.

1 *S: The security doors in some communities seem to use magnetic suction and then use the key to open them.*

2 *T: Use key? What kind of key?*

3 *S: Just the normal key. I'm not sure, I think it's supposed to be a magnetic one*

4 *T: Sit down, please. It might be a little bit like the kind of room card we use at the hotel, isn't that right? Is it what do you mean? A magnetic card.*

5 *S: Just the normal key.*

6 *T: Normal key? That's the unlock function. Other students?*

(Lily, M2-O)

Lily's Q&A session is not so smooth compared to Jack. Situations arise to disrupt the smoothness including that the student's answer is unexpected, Lily does not respond effectively to the student's answer, and the student's reaction is not positive.

Lily tries to explain the access key as a magnetic card, but the student does not agree. The student might not know how it works, but thinks it might relate to magnetism. Lily could directly cite the principle of a magnetic lock and ignore whether the tool is a key or a card. This does not directly deny the student but can transition to the magnetic phenomenon in life naturally.

1 *S: The way we had learnt in the junior school is to put a magnetic needle in the place to be tested and see if it has deflected, and then if there is a deflection, the direction of its the North Pole pointing at is in the positive direction.*

2 *T: The positive direction?*

3 *S: The direction of the positive charge.*

4 *T: The direction of the positive charge? It is not accurate, after this class, I believe we would have a more accurate understanding of the magnetic field.*

(Lily, M2-O)

Lily's response is not accurate, but the student's comment said is wrong. There is no problem with the test tool, magnetic needle, but the North pole in the magnetic field refers to the direction of the magnetic field. Lily does not notice, and feels there is no time to explain (section 4.5).

1 *T: Question 1 Have you ever studied the field? What field has been studied?*

2 *(12s)*

3 *S: We just studied the electric field this semester.*

4 *T: Electric field, then, question 2, How to describe the strength and direction of the electric field? how to describe the strength and direction of the electric field? (10s) You.*

5 *S: To describe the electric field strength and direction, we could use the electric field strength.*

6 *T: Introducing the electric field strength to describe the strength and direction of the electric field. Then, any other opinions? Is there any more intuitive way to describe it? More intuitive methods?*

7 *S: Imaginary electric field line*

8 *T: Very good, the electric field line. Then, question 3, How to describe the strength and direction of a magnetic field? (8s) What you can do with the magnetic field and the electric field? (10s) Analogy! Ok, then question 4, How do you understand the magnetic induction line? Group discussion.*

9 *[Group discussion]*

(Lily, M2-O)

In this Q&A session, the students are not active. No-one answered for about 10 seconds after Lily asked the questions, and Lily needed to name or point to one student to answer. When the third question was raised, Lily answered directly after 10 seconds of silence and made question 4 the topic of the group discussion to break the deadlock. This situation arises not because the students don't know the answer, nor Lily's questions are not clear. Lily's solution is to change Q&A to group discussion, hoping that students will achieve the purpose of checking their knowledge. The unexpected circumstance arises when Lily assumes that the students have comprehended the knowledge without formal instruction. Consequently, she is caught off guard and fails to devise a contingency plan when met with silence or non-standard responses to what she perceives as an elementary question.

1 *T: Is the magneticity of each area on the magnet the same? You, please. One magnet, is the magnetism the same in each area of it?*

2 *S: I think it should be the same.*

3 *T: A magnet, each part of it, its magnetic strength is the same?*

4 *S: en... Its magnetic field is same everywhere?*

5 *T: a magnet, each part of it is the same on the ability to attract iron, cobalt and nickel?*

6 *S: The magnet, the magnet is the same. Magnetic field, each part is the same.*

7 *T: I only ask for the ability to attract iron, cobalt and nickel.*

8 *S: You mean is it the same that the ability to attract iron Cobalt Nickel respectively?*

9 *T: Each part, each area, the magnet, each part and each area.*

10 *S: I think is all the same.*

11 *T: A bar magnet, each part of it has the same magnetism?*

12 *S: Yes, I guess so.*

13 *T: Well, please sit down, any other opinions? You, I just saw that you were laughing. What do you think?*

(Sophia, M3-O)

The student who answers this question might not understand the question, Nevertheless, **Sophia** does not change the question, but asks it repeatedly. After asking the same question five times, the standard answer is not obtained. Sophia asks another student. This implies Sophia does not anticipate that the student would answer incorrectly, and does not make corresponding changes.

Sophia is fluent in expression and the process seems to be smooth, as a result of her extensive practice (section 4.5). Sophia repeats her classroom teaching, and does not think well. She might not reflect on the meaning of the teaching process and solutions to problems. Such teacher training methods might enable teachers to familiarise themselves with teaching content quickly, but do not guarantee ‘quality’. What is trained is not a teacher, but a teaching machine, which can only repeat pre-set questions.

In the Chinese educational environment, knowledge worth teaching is not teacher determine, but the teacher does control how to teach. Regarding the background of the lesson in this study, the significance of Sophia's lesson is that Sophia face an unfamiliar classroom different from the previous ones, to test their rigorous language and on-the-spot adaptability. This is also the purpose of studying the lesson.

'*I just saw that you were laughing. What do you think?*' (Sophia) This sentence notes that aa student is laughed at by his classmate, and implies that the student who laughed at others should know the answer, otherwise there is no right to laugh at others (section 4.5).

T: It’s very simple to knowledge that a magnetic field exists around the magnet, but there is a magnetic field that exists around the current, here, is a famous phenomenon discovered by a famous scientist.
SS: Oersted
SS: Faraday
T: Oersted, Faraday, hum, Oersted's experiment, write it down, Oersted's experiment. Write it on the side of your notebook, Oersted found that the current can generate a magnetic field. What about Faraday? [What] Faraday [discovered] is the generator, which verified the magnetism could generate electricity.

(Oliver, M5-O)

Leo and **Oliver** are familiar with their students, and the teaching process seems meet their expectation. Oliver's class occurs that the student's answer is not satisfied. Oliver hums in a playful tone and then explains the relevant knowledge. This interaction seems to be smoother and more reasonable than Sophia’s, and this is based on the understanding of his students.

Topic F:

As mentioned in the previous section (5.3.1), Charlie, Ava, George and Oscar teach the content of magnetic flux density in the next lesson. Therefore, magnetic induction strength is no longer a learned knowledge (the textbook studied magnetic induction strength before this topic, section 4.3.2). **Charlie** does not make corresponding adjustments, and regards the magnetic field strength as a student's existing knowledge, leading to difficulties in teaching (shown in the following example).

T: What factors may be related to the amount of Ampère force? Let's start the discussion
[Group discussion]
T: If you know the answer, just speak it out. The discussion is over. This group, please. Can you share your opinions?
S: It may be related to the amount of current, also related to the length of the wire. Em...
T: Is there anything else?
S: It may be related to its material.

8 *T: Oh, also related to the material.*

9 *S: That's all.*

10 *T: Please sit down. Please stand up again, I just want to communicate with you, don't be too nervous, love. It is related to the material, do you mean that it is related to the resistance of this conductor?*

11 *S: En.*

12 *T: Well, please answer it, this is a foil tube, will its resistance change before and after the power on?*

13 *S: No change*

14 *T: No change, then it will feel the force both when the power switch on and off, and at this time its resistance is constant, then do you think that the amount of Ampère force is related to resistance?*

15 *S: I guess not.*

16 *T: Ah, ok, please sit down. Are there any other groups that have any other ideas? That group*

17 *S: I think it might be related to magnets.*

18 *T: That means the magnets? Give us more details, please.*

19 *S: Different magnets may have different forces, on the same energized wires.*

20 *T: I add something for you, you just say right or wrong. Do you mean the strength of the magnetic field generated by a magnet?*

21 *S: Yes.*

22 *T: Good.*

(Charlie, F1-O)

The material of the wire and its resistance are not equivalent. The student thinks resistance is related to the material. Charlie leads the answer to 'resistance' ending the process of conjecture and exploration with logical reasoning. When the student refers to the magnetic field, Charlie directly gives the term magnetic field strength. Charlie does not carry out a corresponding experimental investigation and uses verbal guidance to teach student to get a standard answer. Charlie thinks that the students are high achievers, therefore, they must have self-taught relevant content in advance (section 4.5). This phenomenon appears in other teachers' classrooms. Students' guesses become standard answers. Experimental verification only verified the physics quantities in the formula. Experimental inquiry has become a decoration, confirming physics knowledge, and there is nothing to explore.

Topic E:

The previous knowledge students required before this lesson is Coulomb's Law. Ivy and Ella ask students to describe Coulomb's law in the form of question and answer (Example 1). Mia and Luna use language to invite students to recall Coulomb's law (Example 2). Emily, Daisy and Hannah use demonstration experiments in the review stage, guiding students' review of prior knowledge through visible experiments Example 3).

Example 1

1 *T: First of all, Let's recall what we had learned yesterday - Coulomb's law. If there are two units of positive stationary charges in the vacuum with charge q and Q, and the distance they are apart is r. what is the Coulomb Force of the q? You, please.*

2 *S:* $F=kQq/r^2$

3 *T: Can you tell me the direction of the force?*

4 *S: The direction of the force is*

5 *T: they are the same type of charge*

6 *S: Horizontal Right*

7 *T: The direction of that force is directed away from it if they are both of the same types of charge*

8 *S: It should be*

9 *T: It should be along the line. And Q will also be acted the force by the small Q. the direction should be level left along the wire This is the Coulomb's law we learned yesterday.*

(Ivy, E1-O)

Example 2

10 *T: What you just learned last class? That is called? What did you learn in the last class? What is the topic of the last class? Coulomb's law. Right. What is Coulomb's Law? The interaction between charges. Need to contact? No. Then the interaction between charges, how does it happen? Let's study this problem today. ...*

11 *[The computer do not work]*

12 *T: Hey, it is so embarrassing. It does not work. Then, did I leave the homework for you yesterday? Then you should have previewed the content on page 10. Then take a look now...*

(Mia, E2-O)

Example 3

13 *T: ...Then let's recall now. We had learned in the last lesson, between charge and charge? Between charge and charge, there is Coulomb force. How does the Coulomb force work? What kind of force does it belong to? Next, let's do a small experiment...*

14 ...

15 *T: ...Then let's think about it again. When we were in the last class, we studied Coulomb force,*

and we had done such an experiment...

(Emily, E3-O)

5.3.3 *Pedagogical strategies*

This section analyses instructional strategies, classroom management and classroom discourse and interaction used in the seventeen lessons. These aspects run through the entire classroom in time and are intertwined. The teaching strategies involve teacher-student interaction. Teacher-student interaction is sometimes used for classroom management. The purpose of classroom management is to implement the teaching strategies smoothly.

Table 5.3 shows the main instructional strategies used in each lesson.

Table 5.3 Instructional methods used in the lessons

Code of Class	Teachers' pseudonym	Instructional Methods
M1	Jack	Lecture, classroom discussion, demonstration experiment, group experiment
M2	Lily	Lecture, classroom discussion, demonstration experiment, group experiment, exercise and assignment
M3	Sophia	Lecture, classroom discussion, demonstration experiment, group experiment, and assignment
M4	Leo	Lecture, classroom discussion, demonstration experiment, group experiment, exercise and assignment
M5	Oliver	Lecture, exercise and assignment
F1	Charlie	Lecture, classroom discussion, demonstration experiment, group experiment, and assignment
F2	Ava	Lecture, classroom discussion, demonstration experiment, group experiment, and assignment
F3	George	Lecture, classroom discussion, demonstration experiment, and assignment
F4	Oscar	Lecture, demonstration experiment, group experiment, and assignment
F5	Freddie	Lecture, demonstration experiment, exercise and assignment
E1	Ivy	Lecture, demonstration experiment, and exercise
E2	Mia	Lecture, classroom discussion, demonstration experiment, and exercise
E3	Emily	Lecture, classroom discussion, demonstration experiment, exercise and assignment
E4	Ella	Lecture, demonstration experiment, exercise and assignment
E5	Daisy	Lecture, classroom discussion, demonstration experiment, exercise and assignment
E6	Hannah	Lecture, classroom discussion, demonstration experiment, exercise and assignment
E7	Luna	Lecture, classroom discussion, demonstration experiment, exercise and assignment

These teachers are inclined to use whole class instructional strategies. Lecture and demonstration experiments are involved in every lesson. Classroom discussion and assignment are common teaching methods used by fourteen teachers (Table 5.3). Group experiments and exercises have different distributions according to topic. Topic M does not involve physics formulas, so no mathematical calculations are required. This topic introduces physics phenomena and concepts to students, so teachers to use group experiments. Topic F and E involve physics formulas, so to illustrate application in test questions, teachers increase the proportion of exercises (section 4.5).

Teacher-student interaction is evenly distributed in every teaching step, in the IRF/E pattern initiated by the teacher (Appendix 4).

Teachers use classroom management at the beginning and end of the lesson. Teachers utilize salutations and concluding remarks as a means of capturing students' focus, signifying the commencement of class or the conclusion of a lesson with an assignment of homework and consolidation of knowledge. When teaching content conversion or students' inactive response, teachers modify the instructional materials in order to captivate students' interest and provide a more comprehensive explanation of the pertinent subject matter. (Appendix 4).

5.4 The relationship between the semantic waves and the context of classroom discourse

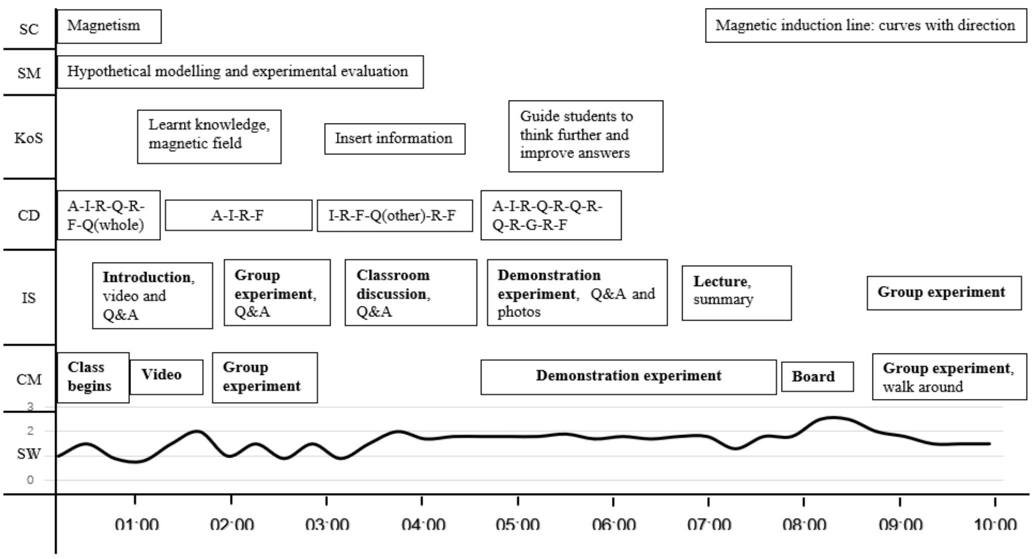


Figure 5.17 The correspondence diagram of semantic waves and semantic backgrounds (M1-O)

The fluctuation of the semantic waves forms under the mutual influence and superposition of different language backgrounds (Figure 5.17). The semantic waves are not determined by a single background form. For example, theoretically, the semantic waves of the teaching language about the physics definition and laws should fluctuate at 2 and above. In the actual semantic wave, the amplitude of the fluctuation sometimes drops to around 1. Amplitude is affected by the teacher's teaching strategies and the actual situation of teaching. Jack introduced the relevant pre-knowledge of magnetism in the form of classroom question and answer, in which the language of the students' answer and the language of the teacher's interpretation for the students to understand would cause the semantic wave to fluctuate around 1. Another example, the semantic wave of the teaching language of classroom management should theoretically fluctuate around 1, yet in reality, there are semantic waves that fluctuate in the range of 2 and above. This is because teachers use repetition or raising the tone to introduce physics concepts and laws to remind students to listen carefully. The semantic wave fluctuates between 1-4 under the mutual influence of different teaching activities.

Although the semantic waves forms under the interaction of different teaching backgrounds, the corresponding teaching activities can be distinguished from the waveform of the semantic waves. In the previous section of the basic waveforms (section 5.2), the basic waveforms have corresponding teaching activities. Small fluctuations, that is, fluctuations between 1-2. In Topic M that do not involve diagrams and formulas, small-amplitude waves run through the entire lesson. When explaining physics concepts and laws, the waves tend to fluctuate around 2. When performing classroom management or combining with daily life, the waves fluctuate towards 1. In Topic F and E involving diagrams and formulas, small-amplitude waveforms also run through the entire class. The difference is that the large-amplitude waveforms are interspersed in the small-amplitude ones. The small-amplitude waveform in this case corresponds to the introduction of teaching, the explanation of physics concepts and laws, classroom management, or the interlanguage among teaching activities. Large-scale waveforms correspond to the introduction of diagrams and physical formulas, appearing in the knowledge summary, and classroom exercises. There are gaps in the semantic wave in some courses. The teacher has not arranged any classroom activities, and there is no language explanation. The semantic waves at this time is blank. The appearance of the flat line waveform corresponds to teachers letting students carry out classroom activities, such as exercises, student discussions or reading books to find corresponding answers, while the teachers walk around the classrooms.

5.5 Summary

Classroom semantic waves have four basic waveforms: small fluctuations, large fluctuations, flat lines and blanks. Classroom semantic waves of the same topic show similar trends to a certain extent. In general, large fluctuation waveforms appear after small fluctuation waves, which is the latter part of the lesson.

Small fluctuations between 1 to 2 (the semantic waves shown as Figure 5.10) are common in the classroom discourse of each teacher. Small fluctuations, that is, fluctuations between 1-2. The content of the utterance does not involve illustrations and formulas.

The rise and fall of the semantic waves with small fluctuations are determined, on the one hand, by the distinction between abstract concepts or rules (2) and real-world examples or instructions (1), which involves the classification and formality of the language. On the other hand, it is determined by the framing of the language.

Large fluctuations between 1 to 4 (the semantic waves shown as Figure 5.11, Figure 5.12, and Figure 5.13) only appear in Topic F and Topic E. The semantic wave reaches 4, which indicated that the teacher involves in analysing the relationship between the physics quantities. The semantic wave reaches 3, which shows that the teacher explains in combination with diagrams. There are three manifestations of large fluctuations, single peak, crest group and trapezoidal wave.

Flat-line (the semantic waves shown as Figure 5.14) are the semantic waves that are without any fluctuation. Some flat lines correspond that teachers let students carry out classroom activities and patrol the classroom. The percentage of time that the flat-lines appear in each class is low. Furthermore, the position of the flat line is relatively irregular. However, the amplitudes of the flat lines are all-around 2, indicating that the discourse is introducing concepts or laws.

During the **blank space** time, the teacher has not arranged any classroom activities, and there is no language explanation. The class is silent.

flat lines and blanks show the silence of the classroom, the difference is that the quiet time is reserved by the teacher or generated in the classroom. Furthermore, the flat lines also show a 'preaching' with a single tone and scientific language.

The fluctuation of the semantic waves is formed under the mutual influence and superposition of different language backgrounds (Appendix 5: Discourse structure). Semantic waves are not determined by a single background form. Since semantic waves are formed under the interaction of different teaching contexts, the corresponding teaching activities can be distinguished from the waveforms of semantic waves.

Semantic waves present in each class is equivalent to the superposition of the semantic waves of various teaching contexts in the classroom. When introducing the definitions, formulas, and relationships of physical quantities of content knowledge, the teaching discourse is presented with semantic waves of 2 and above. The semantic wave of teaching discourse decreases when teachers make relevant interpretations or analogies in life. When the scientific method becomes explicit, the teaching discourse presents a semantic wave of 2 and below. When it implicitly appears in teaching activity, the semantic wave fluctuates with the teaching activity. When the discourse includes the characteristics of learning status, teaching discourse is more inclined to present a semantic wave similar to that when introducing subject matter knowledge. When the discourse includes students' status, the teaching discourse presents a semantic wave similar to that of classroom management. Classroom management usually uses more life-oriented language, and the semantic wave is close to 1. Occasionally, although the teacher is explaining concepts and knowledge, he or she reminds students to pay attention to the lecture by increasing the volume. When the discourse referring to instructional strategies, according to different teaching strategies, teaching discourse presents different semantic waves. When the teacher interacts with students, the teacher makes certain adjustments according to the students' answers. If the students answer correctly and smoothly, the interaction between teachers and students is more inclined towards the professional language of semantic waves at 2 and above. On the contrary, semantic waves of teaching discourse fall. When teachers want to inspire students to think further, they also actively reduce the semantic waves of discourse to assist students in thinking. When teachers want to standardize students' scientific language use, they take the initiative to enhance the semantic wave of discourse. These dimensions affect the presentation of teaching discourse as the immediate context of teaching discourse.

The superposition of their respective semantic waves over time forms the semantic wave of the whole class teaching discourse. This research expects to transform and disassemble the 'signals' conveyed by classroom teaching discourse and discover the laws in it, and the initial results have been achieved.

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Chapter 6 Discussion and Conclusion

6.1 Introduction

This research analyses the classroom discourse of Chinese upper-secondary school physics teachers to answer three research questions:

1. What is the semantic context of post-16 Chinese students' physics lessons? (section 6.2)

2. What is the visual representation of teacher discourse's semantic waves in post-16 Chinese students' lessons on forces, mechanics, electricity and magnetism? (section 6.3)

3. What is the relationship between the semantic waves of post-16 Chinese students' lessons discourse and semantic context? (section 6.4)

Through text analysis, classroom observations and teacher interviews, this research conducted in-depth research into the classroom teaching of three aspects of upper-secondary school electromagnetics. It analyses the semantic waves and contexts of teaching discourse and combines these with an existing scientific classroom discourse analysis framework. This chapter combines the previous two data analysis chapters.

Section 6.5 delves into the current research findings, exploring pertinent aspects. Section 6.6 discusses the limitations of the research, focusing mainly on methodological considerations. Following this, section 6.7 introduces the implications of this study, proposing a new analytical perspective on classroom discourse and offering recommendations for future research that have arisen during the research process and from the conclusions drawn in the study.

6.2 Research question 1: What is the semantic context of post-16 Chinese students' physics lessons?

The concise answers to the sub-questions are outlined below and will be elaborated upon extensively in subsequent paragraphs.

Sub-question1.1 What are the scientific concepts and methods involved in the specific topic?

The content knowledge presented by teachers in their instruction primarily derives from textbook. The knowledge contained in the textbook is demonstrated and discussed in section 4.3.2 and 4.3.3. The content knowledge reflected in the teaching design (section 4.4) and actual teaching (5.3.1) is basically consistent with the textbook.

Teachers have a vague understanding of scientific methods and reasoning (section 4.5.1).

Sub-question 1.2 What is the students' situation that influences teaching?

Students' prior knowledge and misconceptions (section 5.3.2, 4.4 and 4.5)

Students' academic performances (section 4.5)

Sub-question 1.3 What factors influence instructional practices?

Physics content and teaching suggestions in the textbook (section 4.3).

Teachers' understanding of teaching content (section 4.4 and 4.5)

Interaction in teaching (section 5.3)

Teacher and students' background (section 4.2)

Sub-question 1.4 How do teachers handle these factors within teaching?

Teachers synthesize the knowledge structure and requirements of teaching materials, students and their situations to design teaching plans (section 4.3).

Improvise with experience (section 4.5, 5.2 and 5.3)

Instructional design is multifaceted. From the teacher interviews, teachers know that theoretically, they should prepare lessons from the three aspects of textbook, students and teaching techniques, and the format of instructional design is uniformly required. The curriculum standard recommends that teachers establish the instructional objectives and contents in alignment with the curriculum standard and textbook (MoE, 2017b).

The teaching knowledge and teaching suggestions contained in the teaching materials are clearly displayed in Table 4.5, Table 4.6, Table 4.7, Table 4.10 and Table 4.12. As discussed in Section 4.4, the present findings show that, based on the teaching suggestions formulated in accordance with curriculum standard and textbook (CUT), teachers modify their teaching content and adjust the teaching structure by incorporating their instructional style and considering the evaluation requirements of open classes. The changes in the knowledge structure include the exchange of order and the deletion of content.

To gain a comprehensive understanding of the Chinese upper-secondary school physics textbook, this study incorporates two additional textbooks for comparative analysis. By examining the similarities and differences among different versions of these textbooks, this study aims to extract valuable information conveyed within their content.

The analysis of the Chinese upper-secondary school textbook reveals that this resource offers users a certain degree of flexibility and simplifies professional terminology. However, in comparison to AQA and Chinese lower-secondary school textbooks, it falls short in providing factual examples and relevant exercises to enhance students' comprehension.

The language employed in scientific discourse diverges from everyday language, encompassing a specialized formality characterized by distinct terminology, notation, and grammar. This formality is not an external attribute of science but rather an intrinsic element that shapes the construction of scientific communication (Halliday & Martin, 1993). The complexity of the language utilised in Chinese upper-secondary school physics textbook (CUT) is moderate across three textbooks. '*Framing refers to the principle regulating the communicative practices of the social relations within the reproduction of discursive resources, that is, between transmitters and acquirers*' (Bernstein, 2003a, p. 31). As a communication tool, language must involve dialogue among language users. The essence of the dialogue is the communicative role of the language user: either giving or demanding, and the exchanging objects-services or information are presented as proposals or orders. The combination of the factors constitutes the four main discourse functions, offer, statement, command and question (Halliday & Matthiessen, 2004). The sentence types would be imperative (you or you and me), interrogative (WH- or yes/no), and declarative (Halliday & Matthiessen, 2004). The incorporation of sentence type and personal pronouns within the language in CUT reflects its flexible framing, providing users with room for interpretation and engagement (section 4.4.1).

Simplicity of terminology exists in the description of knowledge and the summary of physics laws (section 4.4.2). Researchers have argued whether this pursuit of language concision is effective (Li, C., 2015; Yang, 2020). The establishment of corresponding models or extraction rules is aimed at the simplicity of memory or expression. Such simplicity sacrifices connection with the college physics content.

In scientific reasoning analysis of the textbooks, most space is used to introduce the experiments and mathematical deduction of concepts. Nevertheless, this explicit presentation is limited to merely naming the scientific method to provide students with a mnemonic device and establish a foundation for future learning; its effectiveness in facilitating students' comprehension of scientific reasoning and concepts remains unclear at present. It does not set the corresponding exercises following it, or introduce a large number of scenarios and applications (section 4.3.3). It is imperative to *incorporate exercises and real-world applications* in teaching to compensate for this deficiency.

The teacher incorporated examples and exercises into the instructional design. For Topic M, the introduction chapter of magnetism, Oliver, Sophia and Leo add physics history and clarified their role, patriotism education. Oliver and Leo add exercises, Freddie in Topic F has added numerous exercises. The seven teachers in Topic E have added corresponding classroom exercises to strengthen students' understanding of knowledge. Teachers reorganised the knowledge according to different understandings of concepts and teaching focus.

Knowledge of students should be a part of teaching preparation. In the process of actual teaching preparation and teaching implementation, the influence of knowledge of students mostly exists in the form of recessive. Shulman (1987, p. 8) included ‘knowledge of learners and their characteristics’ as a teacher knowledge base component. Findings from teacher interviews and teaching plans shows that students' prior knowledge is an important content that affects teaching. In the interview, Oliver and Ivy mentioned that the influence of understanding students on teaching is not important. I would argue that the acquisition of knowledge by students holds significant importance, and its impact on teachers' language proficiency and comprehension of subject matter remains implicit (section 5.3.2). In Kind’s PCK structure, knowledge of students is presented as a bridge between pedagogical knowledge and content knowledge (Kind & Chan, 2019). In classroom teaching, teachers need to express content knowledge in a way that students can understand.

The seventeen teachers are inclined to use whole class instructional strategies (5.3.3). The selection of teaching methods constitutes a crucial aspect of teachers' pedagogical considerations, encompassing the arrangement of instructional materials and the allocation of teaching time (section 4.5). In classroom teaching, the organisation of diverse teaching materials serves as a mechanism for teachers to manage their classroom (section 5.3).

Textbook (CUT) serves as essential resources for teachers and students, providing them with fundamental knowledge and materials while allowing flexibility for teaching and learning content customisation (section 4.3, 4.4 and 4.5). In the instructional design process, teachers meticulously consider the teaching materials' content, integrating it with students' existing knowledge to make appropriate additions or omissions in teaching (section 4.4 and 4.5). Teachers adhere to their planned teaching designs throughout the instructional process, simultaneously assessing students' performance and enhancing discourse comprehensibility by incorporating explanations or examples (section 4.4, 5.3 and 4.5). The responses obtained from teacher interviews unequivocally validate these aspects.

6.3 Research question 2: What is the visual representation of teacher discourse's semantic waves in post-16 Chinese students' lessons on forces, mechanics, electricity and magnetism?

Sub-question 2.1 What are the common waveforms of semantic waves?

Classroom semantic waves have four basic waveforms: small fluctuations, large fluctuations, flat lines and blanks (section 5.2.4, p. 188).

Sub-question 2.2 What is the significance conveyed by these common waveforms?

Small fluctuations, that is, fluctuations between 1-2. The content of the utterance does not involve illustrations and formulas (section 5.2, p. 156).

Large fluctuations reaches 4, which indicated that the teacher involves in analysing the relationship between the physics quantities. The semantic wave reaches 3, which shows that the teacher explains in combination with diagrams (section 5.2, p. 156).

The flat-lines are the semantic waves that are without any fluctuation (section 5.2, p. 156).

During the blank space time, the teacher has not arranged any classroom activities, and there is no language explanation. The class is silent (section 5.2, p. 156).

Sub-question 2.3 How could linguistic expressions be converted into waveforms?

Based on Maton’s (2013) semantic plane, this study proposes a new semantic wave recognition system, which can classify classroom discourse into four-quadrants and label them I-IV (section 2.3.5, p. 42); according to Halliday and Martin’s (1993) notion of formality, Bernstein’s (2003a) framing theory, discriminating the small changes between the grade data can be realized (section 2.2.4, p. 37).

Based on Maton’s (2013) semantic plane, this study proposes a new semantic wave recognition system, which classifies classroom discourse into four-quadrants, labelling them as I, real world examples or instructions; II, abstract concepts or rules; III, specific real world examples or figures; and IV, physics equations (section 2.3.5, p. 42). The rise and fall of the semantic waves with small changes are determined by Halliday and Martin’s (1993) notion of formality (terminology and notation, nominalisations, passive voice, and syntactic complexity), Bernstein’s (2003a) framing (sentence type and person pronouns), discriminating the small changes between the grade data can be realized (section 2.2.4, p. 37). The language used by teachers in the introduction process is life-oriented and does not have subject specifications, and formality is low. The semantic wave downs. When teachers teaching about the concepts, specific terminology is involved in each sentence, the formality is high. The semantic wave rises. The framing of language applies in the same way. The assignment takes into account formality and framing, which can overlap or counterbalance.

Classroom semantic waves of sample classroom teaching videos have four basic waveforms: small fluctuations, large fluctuations, flat lines and blanks (section 5.2.4, p. 188). Classroom semantic waves of the same topic show similar trends to a certain extent. In general, large fluctuation waveforms appear after small fluctuation waves, which is the latter part of the lesson.

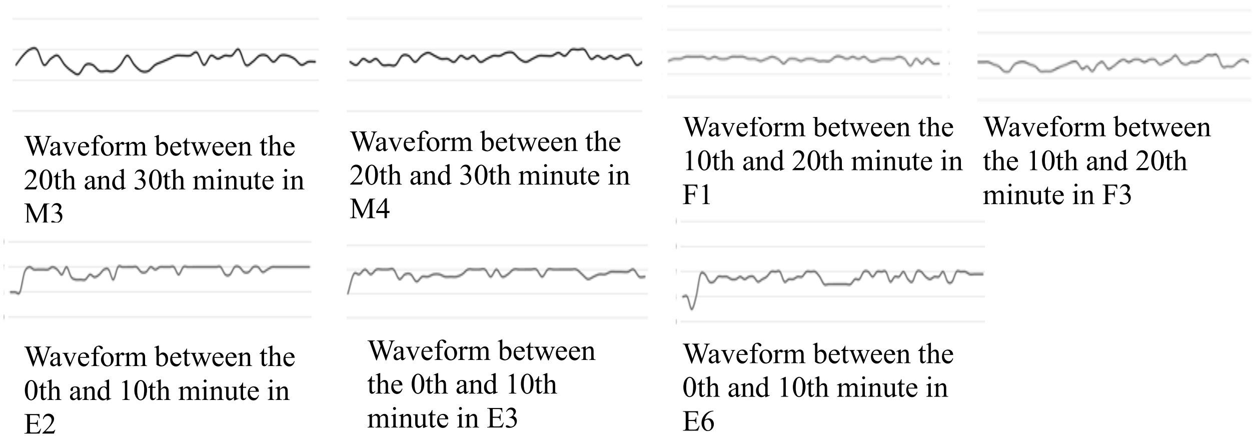
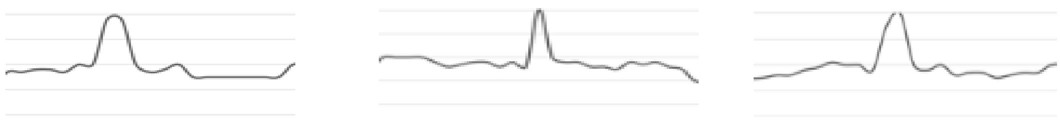


Figure 6.1 The examples of small fluctuations between I to II

Small fluctuations are common in the classroom discourse of each teacher. Small fluctuations, that is, fluctuations between I-II. The content of the utterance does not involve illustrations and formulas. The semantic wave waveforms of the five teachers in Topic M all shows small fluctuations. This is in line with the teaching content of Topic M. As had mentioned in the previous section, the description of the magnetic field's nature is the basis for learning electromagnetic knowledge in the future (Ke & Ma, 2016; Peng, 2009). This topic introduces the underlying magnetic phenomena, magnetic effects, and geomagnetic fields based on relevant knowledge taught in secondary school (MoE, 2017b; Peng, 2009). The maximum amplitude of the wave is around II. The semantic wave of Topic M fluctuates between I-III. According to the changes in the classroom content, the waveform jumps in different intervals. Semantic waves are mostly concentrated around II and drop to interval I at the beginning and end of the class and other limited-time points. It shows that classroom discourse is mostly focused on the explanation of abstract concepts and laws. The occasional life-like language is used to visualize concepts or conduct classroom management. In the semantic waves of Topic F and Topic E classroom discourse, a considerable part of the waveforms shows small fluctuations. The corresponding teaching behaviour is introduction and classroom activities.

Large fluctuations are only observed in Topic F and E. The semantic wave reaches IV, indicating the teacher's involvement in analysing the relationship between physical quantities. Additionally, the semantic wave reaches III, demonstrating that the teacher explains concepts in conjunction with diagrams. These observations highlight three significant manifestations of large fluctuations.

⁕ Single peak



Waveform between the 0th and 4th minute in E4

Waveform between the 35th and 40th minute in

Waveform between the 31th and 38th minute in

Figure 6.2 The examples of single peak

A single crest means that no other large wave crests appear within five minutes before and after the crest. The teacher or student describes the experiment process and conducts experiments, describes the relationship between physical quantities (single peak), and then further introduces the prerequisites and the meaning of each letter (e.g. Charlie, F1-O, Appendix 5, p.328; George, F3-O, Appendix 5, p.330). Alternatively, at the commencement of the lesson, the teacher revisits the content learned in the previous lessons, solely addressing interrelated formulas or physical quantities (e.g. Ivy, E1-O, Appendix 5, p.323; Ella, E4-O, Appendix 5, p.326).

⁕ Crest group

Waveform between the 15th and 19th minute in E3

Waveform between the 31th and 34th minute in E5

Waveform between the 32th and 35th minute in

Figure 6.3 The examples of crest group

The waveforms that appear concentrated with large amplitude peaks are the crest groups. When the teacher is disassembling the formula, introducing the relationship between the physical quantities, interspersing with students in the middle, introducing the prerequisites or operating the experimental equipment, the crest group appears. (e.g. Emily, E3-O, Appendix 5, p.335; Daisy, E5-O, Appendix 5, p.337; Ava, F2-O, Appendix 5, p.329)

⁕ Trapezoidal wave

Waveform between the 25th and 30th minute in F1

Waveform between the 25th and 30th minute in

Waveform between the 13th and 16th minute in E1

Figure 6.4 The examples of trapezoidal wave

Trapezoidal wave refers to the existence of a continuous wave with a large amplitude, which is shaped like a trapezoid. The teacher concentrates on introducing the mathematical relationships between diagrams, formulas or physical quantities, without inserting explanations and examples. (e.g. Charlie, F1-O, Appendix 5, p.328; Oscar, F4-O, Appendix 5, p.331; Ivy, E1-O, Appendix 5, p.333)

Waveform between the 17th and 18th minute in F5

Waveform between the 0th and 2th minute in M4

Figure 6.5 The examples of Flat-line

The flat-lines are the semantic waves that are without any fluctuation. Some flat lines correspond that teachers let students carry out classroom activities and patrol the classroom. The percentage of time that the flat-lines appear in each class is low. The position of the flat line is relatively irregular. However, the amplitudes of the flat lines are all-around II, indicating that the discourse is introducing concepts or laws. (e.g. Freddie, F5-O, Appendix 5, p.332; Leo, M4-O, Appendix 5, p.326)

During the blank space time, the teacher has not arranged any classroom activities, and there is no language explanation. The class is silent. The blank emerged in the classes of F3 (Appendix 5, p.330) and F4 (Appendix 5, p.331), where George and Oscar were engaged in setting up experimental equipment. During this period, no student activities were organised nor any explanations provided. Although the blank was observed solely in two teachers' classes, it has been incorporated as one of the waveforms in the final analysis of this study.

The flat lines and the blanks show the silence of the classroom, the difference is that the quiet time is reserved by the teacher or generated in the classroom. Furthermore, the flat lines also show a ‘preaching’ with a single tone and scientific language.

In Topic M, the five teachers have in common is that they use a more life-oriented language in classroom management. Except for Oliver, they have designed various classroom activities in the classroom, such as group discussions, group experiments and demonstration experiments. The difference is that Jack uses easier-to-understand language to ask questions and guide students to understand and further think about the problem, like supporting students to study, Lily tends to use her language rigour as a role model for students while students touch the scientific content. Sophia and Leo tend to maintain a certain degree of language rigour and scientific and make appropriate adjustments at some point. Oliver adds some of his interpretations in the classroom, which would cause the rigour and scientific of the language cannot be guaranteed. The students' responses in class indicate that Jack and Leo's classes proceeded smoothly, with increased student engagement. The students demonstrated relatively standardized and clear language, as well as a relatively accurate understanding of physics concepts. They engaged in appropriate teaching activities that facilitated critical thinking and comprehension. In contrast, Lily and Sophia's classrooms showed lower levels of student activity, likely due to the dense professional terminology used which hindered their understanding of the material. Oliver's classroom appeared lacklustre, with some students even appearing sleepy during the lesson. The use of dense professional terminology mixed with the teacher's interpretation may have contributed to this disengagement. While metaphorical language was employed, it did not effectively enhance knowledge retention among students. Additionally, the teacher's tone was perceived as imperative by the students, potentially impacting their overall learning experience. After a lesson, the only thing left to the students might be the words in the notebook.

In Topic F, in addition to Freddie, the other four teachers all arrange demonstration experiments, group experiments and classroom activities. During classroom activities, the semantic waves of the teacher's words are mostly concentrated between I-II. Most of them are lecturing, without the corresponding diagrams. Freddie replaces activities with several exercises. The prior knowledge of the students in Freddie's class is different from the other four teachers'. As mentioned earlier, the students faced by the first four teachers have not learned the concept and formula of magnetic induction intensity, so this lesson is designed as an inquiry course and a lot of inquiry activities are introduced. Freddie is based on that the students had already learnt the magnetic induction intensity. As a semi-review course, after deriving the Ampère force formula from the magnetic induction intensity formula, Freddie uses exercises to deepen students' understanding. The overall amplitude of the semantic wave of Topic F is larger than that of Topic M, because Topic F involves the schematic diagram of the direction and the Ampère force formula. George and Ava are similar in the form of semantic waves. They arrange the explanation of the direction of the Ampère force first and then explore the magnitude of the Ampère force. The exploration process is described in professional language, and finally, the formula of Ampère force is obtained. Therefore, the semantic wave fluctuates between I-II in about 30 minutes. The semantic wave reaches III or IV in the last 10 minutes (Figure 5.8). George realizes that some time is wasted in preparing the experimental equipment. During lecturing, George drives the time forward a bit, and it can be seen that the semantic wave crest has moved forward. George and Freddie split the formulas and explain them in turn. There are several crests in the semantic wave (Figure 5.8). Freddie uses the schematic diagram to facilitate his explanation. Thus, there will be many several small peaks and gently rising images. Oscar's semantic waves are fragmented, and there are meaningless blanks during his teaching (Figure 5.8). Furthermore, the sequence of knowledge points of Oscar's and Charlie's classes are the same, therefore, the general trend of semantic waves is similar. As Oscar realizes that group experiments and discussions take too long, he accelerates the pace of lectures and shortens the time required for the Ampère force magnitude. It can be seen from the semantic wave image that the waveform trends of Oscar's and Charlie's are the same, except that the peak groups with amplitudes of IV and III are closed.

In Topic E, the overall trends of the semantic waves of the 7 teachers are similar. They reflect that the first ten minutes fluctuate between I-II, and the wave that reaches the peak of IV from the second ten minutes, which continues to the end of the course. It is brought about by the characteristics of Topic E. In the early stage, teachers need to explain and introduce the topic, and then allocate nearly thirty minutes to analyse the formula and the related concepts of electric field strength. Among them, only the classes of Ivy and Ella involves the formula of Coulomb's law or the mathematical relationship between physics quantities. Therefore, the semantic wave of these two classes has a peak of IV at the beginning of the course. The other five teachers review Coulomb's law. They do not expand it further, only mentioning the concept and its definition. The seven semantic waves appears flat lines of different lengths without fluctuations. These flat lines correspond that teachers let students carry out classroom activities and patrol the classroom. The classroom activities include letting students do exercises (Mia, E2-O; Emily, E3-O; Ella, E4-O; Daisy, E5-O; Hannah, E6-O; Luna, E7-O), students discussion (Mia,E1-O; Daisy, E5-O) or reading the book to find the corresponding answer (Ella E4-O; Luna, E7-O).

From the seventeen classroom discourse waves, it is evident that the waveform of discourse on the same topic exhibits a higher degree of similarity, while displaying variations among different teachers. This observation suggests the feasibility of converting discourse into waveforms.

6.4 Research question 3: What is the relationship between the semantic waves of Chinese upper-secondary school physics teachers' discourse and semantic context?

The fluctuation of the semantic waves is formed under the mutual influence and superposition of various semantic contexts.

The semantic wave present in each class is equivalent to the superposition of the semantic waves of various teaching backgrounds in the classroom. The three topics analysed in this study have the following commonalities:

When the teacher's instruction incorporates content knowledge, the wave pattern becomes intricate, encompassing diverse waveforms. Conversely, when the teacher's teaching is tailored to align with students' existing knowledge, the waveform tends to exhibit higher amplitude and closely resembles the language of physics. In instances where the teacher imparts pedagogical knowledge, lower amplitude waveforms exist.

When teachers elucidate the content knowledge, they employ a language that closely aligns with everyday life to explicate physics terminologies. The waveform is attenuated. Upon returning to the realm of physics knowledge in their explanatory conclusions, they adopt rigorous physics language and employ commanding sentence structures such as imperative sentences to underscore fundamental concepts and laws of physics.

When introducing the definitions, formulas, and relationships of physical quantities of *content knowledge*, the teaching discourse is presented with semantic waves of 2 and above. The semantic wave of teaching discourse decreases when teachers making relevant interpretations or analogies in life.

When the *scientific method and reasoning* becomes explicit, the teaching discourse presents a semantic wave of 2 and below. It refers to teachers consciously and explicitly incorporating scientific method and reasoning into their teaching practices and naming them accordingly. By doing so, they aim to develop a deeper understanding of scientific concepts among students. When it implicitly appears in teaching activity, the semantic wave fluctuates with the content of teaching activity.

Knowledge of students encompasses students' existing knowledge as well as any misconceptions they may hold. Teachers typically employ a combination of knowledge review and logical argumentation to explain concepts, employing precise and physics language that aligns with the scientific discourse. The waveform is at a high position

When the discourse including *the characteristics of learning status – prior knowledge and misconceptions,* teaching discourse is more inclined to present a semantic wave similar to that when introducing subject matter knowledge.

When the discourse including *students' status*, the teaching discourse presents a semantic wave similar to that of classroom management. *Classroom management* usually uses more life-oriented language, and the semantic wave is around I. Occasionally, although the teacher is explaining concepts and knowledge, he or she reminds students to pay attention to the lecture by increase the volume.

Pedagogical knowledge involves instructional strategies and classroom management techniques. Teachers use language that is closer to life, and the waveform is in a low position. Occasionally, the implementation of classroom management occurs concurrently with the delivery of subject matter expertise, resulting in a waveform positioned at a high level.

When the discourse referring to *instructional strategies,* according to different teaching strategies, teaching discourse presents different semantic waves.

When the teacher *interacting* with students, the teacher makes certain adjustments according to the students' answers. If the students answer correctly and smoothly, the interaction between teachers and students is more inclined towards the professional language of semantic waves at II and above. On the contrary, the semantic wave of teaching discourse falls, when teachers want to inspire students to think further, they actively reduce the semantic wave of discourse to assist students in thinking. When teachers want to standardise students' scientific language use, they take the initiative to enhance the semantic wave of discourse.

These dimensions affect the presentation of teaching discourse as the immediate context of teaching discourse. The superposition of their respective semantic waves over time forms the semantic wave of the whole class teaching discourse. This research expects to transform and disassemble the 'signals' conveyed by classroom teaching discourse and discover the laws in it, and the initial results have been achieved.

Discrepancies among topics:

Given that Topic M does not involve equations, its maximum crest will not exceed IV. The occurrence of intermittent large waves in Topic F after twenty minutes of small waves suggests a transition toward more complex concepts-equation. In Topic E, the emergence of alternating waveforms consisting of large and small waves after ten minutes indicates that teachers have commenced explaining, calculating, and applying formulas following the establishment of foundational knowledge. Once the formula is introduced, teachers employ life-like language to deconstruct it or organize classroom activities accordingly.

The sample courses examined in this study are specifically designed for upper-secondary school students who possess a solid foundation in both physical and mental development, as well as knowledge acquisition. To enhance students' comprehension, it may be beneficial to incorporate life-oriented explanations alongside the dissemination of knowledge. This approach does not necessarily because students would grasp some concepts without life-like explanations.

Teachers' understanding of their classroom is typically confined to the realm of teaching and knowledge, with little attention given to language. This oversight often results in the inclusion of imprecise content and unnecessary complex sentence structures, which hinders students' learning process and may even impart incorrect information.

The discourse employed in classroom teaching diverges from the objective existence of physics mechanical waves, as individuals harbour their conceptualizations of semantic waves, even when utilizing the same analytical framework. The analytical framework established within this study does not serve as a standardized evaluation tool; rather, it serves to prompt teachers to engage in critical self-reflection regarding their instructional discourse and subsequently implement appropriate adjustments.

6.5 Discussion

This section grounded in the research findings explore the pertinent aspects.

6.5.1 *The distinction between classroom discourse semantic waves and Maton's semantic waves*

Martin (2013) proposed an explanation of the role of teaching in the process of knowledge accumulation (unpacking and then packing). Curzon, Waite, Maton, and Donohue (2020) apply the notion of 'semantic waves' to Computer Science Education. They examine the teaching activities as semantic profiles and drawing a heuristic version. However, they do not pay attention to the rise and fall of every word or sentence, as they say, they draw a sketch.

As discussed in section 4.4 and section 5.2, during the teaching process of design and implementation conducted by volunteer teachers in this study, there is minimal variation among different teachers regarding the fundamental teaching structure and content, as they are all based on the national unified curriculum standard and textbook. Consequently, the disparity in language expression within teachers' classroom discourse has emerged as one of the few distinguishing factors among them. Curzon et al. (2020) utilize semantic wave theory for designing classroom teaching activities does not entail specific teaching discourse but can be applied in a simple manner. Given the unique context of Chinese teachers, this study conducts a comprehensive analysis of actual classroom instruction to capture teacher differences to their fullest extent possible; thus emphasizing the significance of attending to teachers' choice of discourse.

This study operationalizes the semantic plane into four distinct levels and incorporates formality and framing to capture subtle variations between these levels, aiming to accurately represent the nuances in teaching discourse among different teachers on the same topic. The graphical representation of classroom discourse that I have generated successfully achieves this objective.

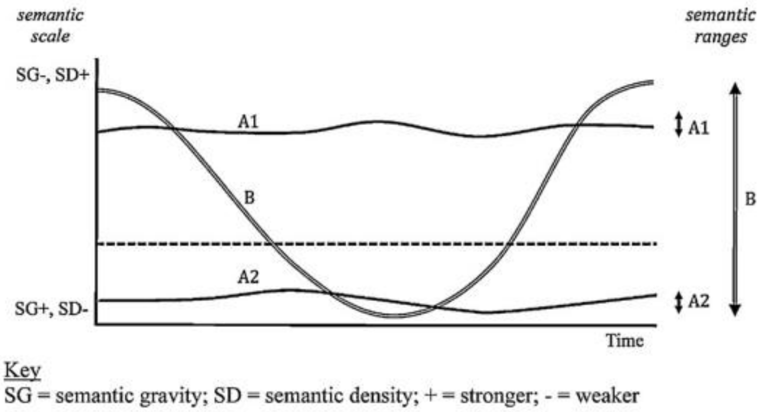


Figure 6.6 Maton's U-shaped semantic wave

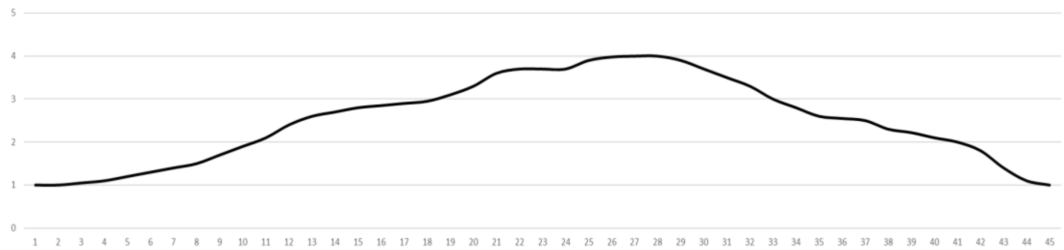


Figure 6.7 45-minute physics classroom discourse semantic wave trend graph

The waveform presented in this study diverges from Maton's U-shaped semantic wave, yet their underlying principles remain congruous. Maton's U-shaped semantic wave elucidates the process of knowledge accumulation, commencing with intricate concepts (challenging terminology) being unpacked and deconstructed into easily comprehensible content for students. Subsequently, these concepts are consolidated to facilitate the construction of interconnected ideas within students' cognitive frameworks. In contrast, the unimodal curve wave pattern observed in my research explicates the classroom teaching process of Chinese upper-secondary physics teachers, which initiates with scene creation aimed at enhancing student comprehension of the prescribed instructional objectives and subsequently introducing physics concepts. These physics concepts are then applied to real-life scenarios. Consequently, a rising-then-falling waveform pattern is manifested accordingly.

Chinese upper-secondary school physics curriculum standard requires the cultivation of the core quality of physics as an important goal of physics teaching (MoE, 2017b). If physics teaching only takes knowledge as the clue, it will lead to the teaching design focusing on knowledge and only focusing on students' acquisition of knowledge, while ignoring the cultivation of students' core competence of physics. Therefore, teachers should implement the cultivation of physics ideas, scientific thinking, inquiry, attitude and other physics competences in their teaching activities and convey these through teaching discourse. In accordance with the curriculum standard requirements, educators are expected to prioritize the rationality of instructional design and the suitability of language articulation, rather than solely focusing on knowledge dissemination.

This study integrates Halliday and Martin’s (1993) notion of formality, Bernstein’s (2003a) framing theory and Maton’s (2013) semantic plane, categorizing semantic wave analysis into semantic blocks with corresponding value range and rules. This framework provides a valuable tool for researchers and teachers to evaluate and analyse teaching practices, emphasizing attention to language expression within each semantic block rather than solely focusing on knowledge transmission and general teaching activities. In Chinese physics education research, current studies tend to follow standard methods with similar results (detailed reviewed in section 2.3.4), often overlooking the importance of instructional language (Song, 2016). My proposed theoretical analysis framework represents a significant breakthrough that offers a new perspective for physics education in China.

I innovatively constructed a semantic wave and semantic context graph, presenting them intuitively through the dimension of time. The semantic wave and context graph visually encapsulates the entirety of the 45-minute class, drawing from established classroom discourse analysis framework (detailed reviewed in section 2.3.2), scientific reasoning theory (Kind & Osborne, 2017), and PCK theory (Kind & Chan, 2019). The ultimate manifestation of this diagram reflects the teacher or researcher's comprehensive reconstruction of the entire lesson. This reconstruction effectively aids teachers in reflexion on classroom instruction and assists researchers in comprehending the panorama of the classroom.

6.5.2 *The potential impact of semantic waves on teachers' teaching*

My contribution is the development and first time application of my recognition system for analysis of teaching discourse, which provide a new visual tool and idea for classroom teaching evaluation and teachers' reflection after class. Especially in Chinese education background, classroom discourse has always been an overlooked point in physics classroom teaching related research (section 2.2.4).

I explored how to transform classroom teaching discourse into images, and has obtained preliminary results, proved the feasibility of describing my semantic waves of classroom discourse, found and analysed the common waveforms of semantic waves shown by the samples in this study, and investigated the corresponding relationship between semantic waves and semantic context

Considering that the science studied is physics, from a physics point of view, all matter in the world has wave-particle duality, and waves are essential matter. Chinese physics teachers are receptive to the concept of classroom semantic waves. Although, it is worth noting that the discourse employed in classroom teaching diverges from the objective existence of physics mechanical waves, as individuals have their conceptualisations of semantic waves, even when utilizing the same analytical framework. The framework established within this study does not serve as a standardized evaluation tool; rather, it serves to prompt teachers to engage in critical self-reflection regarding their instructional discourse and subsequently implement appropriate adjustments based on a holistic view of their teaching.

I have conducted a series of workshops for in-service teachers, explaining my recognition system of semantic waves. During these sessions, I invited volunteer teachers to draw their semantic waves. Despite providing an introduction to my recognition system and necessary precautions, there were still some discrepancies between the waveform diagrams drawn by the teachers and those created by myself. For instance, some teachers may have marked low values for imperative sentences that lacked true meaning of commands. Similarly, when evaluating students' use of physics terms, they may have assigned lower values if they believed that the students did not completely comprehend the terminology being used.

These differences perplexed me. I always try to draw an ideal waveform, one that garners unanimous agreement. As previously mentioned, Chinese education is a highly centralised structure (section 1.1.1). Although Chinese teachers are composed of unique individuals, the influence of Chinese traditional culture and society makes teachers like conformity, so that both communication and teaching can be more efficient. Consequently, when confronted with my semantic wave theory, teachers seek a common waveform as an optimal solution.

After repeated assignments, I realised that perhaps the difference was the meaning of semantic waves. Everyone has their semantic wave in mind, reflecting the content and mood of the person who describes the waveform at that moment. There is no single ‘best’ waveform, only an agreed recognition system.

Everything is a complex unity that encompasses various concrete contradictions, including both primary and secondary ones. Within these specific contradictions, there are also shared elements present in particular contradictions, which can be identified as fundamental or general contradictions.

Basic contradictions could be solved by a set of basic teaching processes which should be shown as the common semantic waveforms. As basic contradictions persist within specific time periods, it consequently dictate the corresponding teaching processes that endure throughout those particular epochs. This forms the common semantic waveforms.

Solving specific contradictions requires specific analysis of specific problems. The specific contradictions are concrete and possess unique characteristics that demand teachers' subjective initiative in designing, planning, and adopting the most appropriate pedagogical approaches based on the teaching object, content, and purpose. This process entails teachers' creation of diverse teaching techniques that culminate in the various waveforms.

6.6 Limitations

Given the many constraints, such as time and place constraints, manpower constraints on independent researcher, current research inevitably suffers from the following limitations:

This study primarily adopts a qualitative research approach, acknowledging that its generalisation, reliability, and validity cannot be directly compared to quantitative research. Nevertheless, given the current circumstances, this methodology appears to be the most suitable option. By employing purposeful sampling and triangulation of data, efforts have been made to enhance the reliability and validity of the findings as much as possible. However, caution should still be exercised when generalising these results to all teachers in China.

This study primarily collects evidence on teachers' implementation practices through teacher interviews and teaching plans, aiming to provide a macroscopic view of classroom discourse. However, it inevitably overlooks valuable insights that can be gained from the students' perspective.

The sample of this study is selected from the 'Good Lesson' project in China. Although these lessons are national programs and serve as role models for teachers across the country, they are inevitably 'open class' that are selected under the 'Good Lesson' criteria (Appendix 2.1), and may not fully represent the content taught in regular classes. At present, it is uncertain whether this analysis approach is valid for regular lessons.

Limited sample size hinders this study's generalisation. The background of this research is the new round of curriculum reform in upper-secondary schools in China. Although teachers feel that they do not need to make too many changes, they still have to participate in the theory training classes, teaching seminars and preparations for a new round of open classes. The teacher's time is not sufficient, and the communication density of the research has not reached the expected level. This research presents a comparison of the teaching discourse among teachers under the same topic and between different topics. However, there is still a lack of comparison between the same teacher on different topics and the same teacher on the same topic facing different students, which could describe the characteristics of the teacher's personal style. Due to the lack of personal time of the teacher, it is impossible for teachers to provide more instructional videos.

As with other qualitative studies, the researcher effect is an inescapable issue. The data collection process affects the data obtained during the process. To avoid the researcher effect, research chose to collect teaching videos recorded by the teacher. However, this practice also inevitably adds a common background to the samples. They are all from the 'Good Lesson' project. Judging from the teacher interview data, the researcher effect seems to have an impact on the participating teachers. They believe that the publication of this research may be transmitted information to policy makers. Some interviewees tend to complain that they are not satisfied with the current teacher promotion system and do not understand the new terms introduced by the new curriculum reform. This vividly reflects the powerful influence of the change of official curriculum on teachers, but the influence on teachers' teaching practice is hidden. Researcher bias exists in data analysis. This study has corrected the bias by assigning values several times and discussing the code system with peers as much as possible.

6.7 Implications and recommendations for future research

As a science classroom, classroom discourse has always been an overlooked point in physics classroom teaching related research. Researchers pay more attention to the scientific aspects of physics classrooms, such as the teaching of the nature of physics, especially for Chinese researchers (Song, 2016). Teachers believe that language is a personal style or a proficiency that can be improved by mechanical repetitive practice. , Lemke (1990, p. ix) said: '*...language is not just vocabulary and grammar: Language is a system of resources for making meanings. In addition to a vocabulary and a grammar, our language gives us a semantics ... The semantic resources of language are the foundation for all our efforts to communicate science and other subjects. To understand how communication works, and what makes it succeed or fail, we need to analyse how we use language to mean something.*' Language is a very important part of classroom teaching.

As far as I am aware, this thesis represents the pioneering qualitative study in China that transforms discourse within upper-secondary school physics classrooms into waveform and subsequently analyses it. It employs a unique theoretical framework that facilitates the visualization of intricate classroom discourse through waveforms. This research assigns values to classroom discourse and fits them into waveforms, and comprehensively examines the semantic context of discourse and its correlation with semantic waves. It compares variations in semantic waves across different topics and teachers, thereby introducing a novel tool for analysing classroom discourse - transitioning from traditional encoding to graphic analysis.

This research provides valuable insights into the exploration of underlying and comprehensive factors evident in classroom discourse, including the embodiment of teacher pedagogical content knowledge (PCK) during classroom instruction, semantic comprehension of classroom discourse, as well as potential linguistic and cultural influences. These findings significantly contribute to our enhanced understanding of the nature and manifestation of instructional practices within the Chinese educational context.

Therefore, this study can serve as a valuable tool for teachers' self-reflection and classroom evaluation. Semantic wave, a more intuitive way to analyse the classroom, can help teachers reflect on their teaching more deeply. Physics teachers also need to consider the influence of language when teaching. In the process of teacher training, we should not only help teachers prepare knowledge, instructional strategies and teaching resources, but also guide teachers to realize the importance of language in teaching.

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This study employs a diverse range of data sources, including teacher interviews, teaching plans, materials, and videos. Involving different data sources has proven to be valuable in collecting basic data to illuminate and interpret classroom discourse. Consequently, the entirety of classroom instruction can be perceived as a comprehensive depiction encompassing multiple factors such as instructional materials, teachers' pedagogical strategies, and the actual interactions occurring within the classroom. This research perceives the semantic wave theoretical framework as a visual representation that encapsulates this holistic view. By triangulating and complementing each other's findings from different data sources, this research enhances reliability and validity. Simultaneously, adopting a novel research perspective that transforms classroom discourse into waves offers enlightening insights for future research.

Future research could collect more data and use big data to fit the base semantic waves of each lesson, which could be used to analyse the teacher's classroom teaching and the teacher's self-improvement. The basic waveform is not what every lesson should be. Actually, it represents the semantic waves of the course covers the basic knowledge in accordance with the existing textbook and curriculum standard, and based on the big data which could remove the teacher’s style and the state of the students. Teachers could increase or decrease the amount of knowledge according to specific situations, and modify the language to form their unique semantic waves. Later, the assignment system can be further programmed to enable one-click analysis of teachers' classroom discourse semantic waves, facilitating a comparative evaluation with corresponding basic waveforms for conducting elementary analysis and providing teachers with reflective tools.

Future research could focus on the significance of the existence of open classes and its direction of improvement. There is a slight difference between the teacher's open class and the normal class. Teachers preparing for the open class would concentrate a lot of energy on designing teaching activities and repeatedly practising and rehearsing the teaching language. Therefore, open classes provide a wealth of teaching resources for normal classes.

Other points can be paid attention to, such as how to carry out patriotism education in the physics classroom, and the influence of female teachers' social status on career development.

6.8 Summary

This research completes the research on Chinese physics classroom teaching and reveals the important position of language in physics teaching. Language is a signal system that conveys meaning. Teacher's expression and student's understanding need this signal system as a medium to accurate operate. This research visualizes this signal system in the form of newly constructed semantic waves and unearths the close dialectical connection between the semantic waves and the semantic contexts. Different semantic contexts have unique semantic wave waveforms. It is the superposition and mutual influence of these basic semantic waves that form the semantic waves of the entire classroom teaching.

Classroom semantic waves have four basic waveforms: small fluctuations, large fluctuations, flat lines and blanks. Classroom semantic waves of the same topic show similar trends. Concept introduction lessons, which do not involve physics quantity relations and mathematical calculations, emerge mainly small-amplitude waveforms, interspersed with flat-line waveforms (like Topic M in this research). The semantic waves in the topics, that include the relationship between physics quantities and mathematical calculations, involve four basic waveforms (like Topic F and E in this research). In general, large fluctuation waveforms appear after small fluctuation waves, which is the latter part of the lesson. On the whole, the semantic waves of physics classroom teaching are unimodal curve (shown in Figure 5.15), passing the opening, developing and concluding part. Classroom teaching would go through the introduction stage (the semantic wave fluctuates around 1). After the introduction and explanation of the concept lasts for about 10 minutes (around 2), the teaching enters the stage of analysing the relationship between physics quantities (2-4), the summary stage (around 2), and then ending the teaching (return to near 1). During the opening, developing and concluding, the semantic contexts, content knowledge, knowledge of students and pedagogical knowledge, interact with each other and weave the classroom teaching discourse.

The exploration of scientific knowledge and rules starts from small phenomena in life, and then conducts thinking and reasoning, and does experimental verification. From the general trend of the semantic waves, teachers reproduced this process in classroom teaching. As Lao Tzu said: 'tú nán yú qí yì, wéi dà yú qí xì' (Lao, Su, & Wang, 2012). Dealing with problems should start from the easy place, and achieving lofty goal should start from the subtle steps. In this process, teachers use teaching props, experiments or examples to reproduce physics phenomena; lead students to imitate the process of scientists exploring the physics knowledge or laws based on their learning and experience; after the knowledge is presented, the teacher connects with the reality of life and introduces the application of knowledge in real life. Some teachers set up group experiments, therefore, students can experience experimental inquiry firsthand. Although exploration of scientific knowledge and rules is extremely complicated and long, a 40-minute class can not exhaust it. Teachers need to design the inquiry process in accordance with the curriculum requirements, combining their characteristics and the status of students, and retrieve a large amount of materials to assist teaching. This requires a platform that can simultaneously integrate and continuously update teaching resources to assist teachers for their teaching design. Open class is a form, it is not limited to this.

I have delineated the process through which I transformed physics classroom teaching into waves. The main contribution of this thesis may be to provide an idea for teaching evaluation, and a reflection tool for teachers, and to clarify the important role of language in physics instruction. This research underscores that teaching physics is not solely about knowledge transmission but also entails skilfully amalgamating diverse information facets to weave compelling narratives. Teachers must possess a profound awareness of language's significance in teaching and engage in continuous self-reflection to cultivate an enhanced classroom teaching.

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V

Appendix 1: Ethics related documents

Appendix 1.1: Ethics Application Form

Durham University
School of Education
Research Ethics and Data Protection Monitoring Form

Research conducted by Staff and Students in the Department is subject to the standards set out in the Department Code of Practice on Research Ethics. The School of Education Ethics Sub-Committee will assess the research against the British Educational Research Association's *Revised Ethical Guidelines for Educational Research* (2011).

Before the commencement of all research this form should be completed, submitted to the School of Education Ethics Sub-Committee, and their response received. No research can be conducted until ethical approval has been obtained. The Committee will be responsible for issuing certification that the research meets ethical standards and will, if necessary, require changes to the research methodology or reporting strategy.

Appeals against the decision made by the School of Education Ethics Sub-committee should be made by email to ed.ethics@durham.ac.uk. Appeals will be heard by the Faculty Ethics sub-committee.

The application should contain:

a. This completed (and signed) application form;
b. Completed **appendix A**:
    a. A summary of the research proposal. This should be no longer than one A4 page that details:
        i. objectives of the study,
        ii. description of the target cohort / sample,
        iii. methods and procedure of data collection,
        iv. data management, and
        v. reporting strategies;
    b. Outline of the interview schedule / survey / questionnaire / observation protocol or other data collection tools (if applicable depending on the methodology you plan to employ);
c. Completed **appendix B**: the participant information sheet (if applicable), and
d. Completed **appendix C**: the consent form (if applicable).

Templates for the summary of the research proposal, the participant information sheet and the consent form are provided as **appendices A-C** and can be amended as appropriate for the particular application.

Please include all the relevant documents above within one combined document (applications can be accepted in MS Word .doc or .docx format only).

Notes:

- **For non-empirical work** please complete your details on page 2, answer Question 1 and provide further details at Question 11 only. None of the appendices are required.
- **As all applications should be submitted electronically in MS Word format.** Electronic (scanned) signatures should be used (please paste an image of your signature into the declaration section).
- There is a **deadline of 15th of each month** for Ethics applications. Applications received by the 15th of the month will be processed within a 2 week turnaround time i.e. approval letters sent out by the end of the month assuming no queries. Applications received after the deadline will go into the next month.
- **No research should be conducted until ethical approval is obtained.**
- Incomplete applications will be returned without consideration.
- **Please send all documents to ed.ethics@durham.ac.uk, School of Education Research Office, tel: (0191) 334 8403.**

Application for Ethics Approval

Name of applicant	Yang Song
Email address	yang.song @durham.ac.uk
Category *[choose from list]*	Postgraduate student - Research programme
If "Other" please specify	
Student ID number *[students only]*	000588896
Programme *[students only – choose from list]*	PhD
If "Other" please specify	
Name of supervisor *[students only]*	Dr. Vanessa Kind
Title of research project	How do teachers make meaning in science class in China? An analysis of Chinese classroom teaching under the newest curriculum
Date of start of data collection phase of the research *[must be a future date – no research to be conducted until ethical approval obtained]*	4th September, 2017
Is the research funded *[staff only – choose from list]*	No
Name of funder *[staff only]*	N/A
Name of Co-Is if applicable *[staff only]*	N/A
Is this application subject to external ethical review? *[choose from list]*	No
If "yes" please specify who	N/A

FOR OFFICE USE ONLY – Please do not delete this box

Please can reviewers enter the date and select the outcome from the drop-down outcome list below? To open the drop-down list, please select "click here to choose from list". To enter a comment, please click on the yellow highlighted area below and start typing.

Please note that as the review process is anonymous there is no requirement to include initials or signatures in this section.

REVIEWER RESPONSE

Date:

Click here to choose from list

REVIEWER COMMENTS

1) a. Does the proposed research project involve data from human participants (including secondary data)?	Yes
b. Is the research project *only* concerned with the analysis of secondary data (e.g. pre-existing data or information records). If yes, please continue with Q6-13	No
c. Is the work non-empirical (e.g. literature review, opinion piece, systematic literature review) If yes, please complete Q11	No
2) Will you provide your informants – prior to their participation – with a participant information sheet containing information about the following: a. The purpose of your research?	Yes
b. The voluntary nature of their participation?	Yes
c. Their right to withdraw from the study at any time?	Yes
d. What their participation entails?	Yes
e. How anonymity is achieved?	Yes
f. How confidentiality is secured?	Yes
g. Whom to contact in case of questions or concerns? *Please attach a copy of the information sheet (template available at* ***appendix B****) or provide details of alternative approach at Q13 of this form.*	Yes
3) Will you ask your informants to sign an informed consent form? *Please attach a copy of the consent form (template available at* ***appendix C****) or provide details of alternative approach at Q13 of this form.*	Yes
4) a. Does your research involve covert surveillance?	No
b. If yes, will you seek signed consent post hoc?	Not applicable
5) a. Will your data collection involve the use of sound or image recording devices?	Yes (if yes, please answer Q5b and Q5c below)
b. If yes, will you seek signed consent?	Yes
c. Please specify the type of recording	Audio and video

6) Will your research report be available to informants and the general public without restrictions placed by sponsoring authorities?	Yes
7) a. Does the research involve unsupervised access to children or vulnerable adults within an activity that is deemed as regulated and would therefore require DBS clearance?	No
b. If yes, can you confirm that DBS clearance is in place or will be in place prior to commencing your research?	Not applicable

8) How will you guarantee confidentiality and anonymity?

As for the classroom observations for classroom teaching and tests for students, data will be collected by the teachers in specific secondary school classes and sent to me in a secure format directly. Furthermore, tests will be completed anonymously using unique student identifiers. Further teacher interviews will be conducted via Skype. The interviewer and interviewee will be situated in private offices. The interviews will be recorded. Interviewees will be given pseudonyms throughout the process. In the final report, all the schools and participants will be given pseudonyms.

9) What are the implications of your research for your informants?

The video recording of classroom teaching will not influence normal teaching process in the secondary schools. The teachers I will observe often record their lessons as a means of improving their teaching skills, hence informants are already used to the technology. In addition, tests will use standardised questions that are applied as regular test in students' daily studies. The interview will prompt teachers to think about their teaching strategies and reflect more deeply on their language and its impact on student learning.

10) Are there any other ethical issues arising from your research?

Both students and teachers will be informed and asked for informed consent prior to the research. Participants have the right to withdraw and decide to quit the project at any time. Interviews are designed for investigating teachers' reflection of their teaching. There will be no other ethical issues.

11) ***For non-empirical projects only***, please provide a brief overview of your project, approx.150 words max. Please include the research aims and objectives and your research approach *(Appendices A to C are not required)*.

12) Will your research either

- Involve the study of an organisation which is proscribed under the terms of the Terrorism Act, or require accessing materials produced by or in support of such an organisation (see https://www.gov.uk/government/publications/proscribed-terror-groups-or-organisations--2)

Or • Involve the study of any other current organisation which, as part of its agreed programme, advocates the use of violence to achieve its aims, or require accessing materials produced by or in support of such an organisation. **If you answer yes to either of the above then please contact** ed.ethics@durham.ac.uk **for an additional appendix to complete.** For further information please refer to the University policy https://www.dur.ac.uk/resources/research.office/local/policy/Security-sensitivematerialsFINAL1.0.pdf
13) Please provide any additional information relevant to your application

Declaration

I have read the Department's Code of Practice on Research Ethics and believe that my research complies fully with its precepts.

I will not deviate from the methodology or reporting strategy without further permission from the School of Education Ethics Sub-Committee.

I am aware that it is my responsibility to inform the organisation in which data collection takes place (e.g., school) that ethical approval from the School of Education Ethics Committee has been given, prior to commencing data collection.

Applicant signature*	Date 13/06/2017
Proposal discussed and agreed by supervisor *[students only]*	Date 19th July 2017

**To enable electronic submission of applications, electronic (scanned) signatures will be accepted.*
Please note that typed signatures cannot be accepted.

APPENDIX A

Appendix A - Summary of the research proposal

Please include : a. A summary of the research proposal. This should be no longer than one A4 page that details:

i. objectives of the study:

This study aims to analyse how teachers make meaning in science classroom through discourse analysis and try to find their theoretical explanations and interrelationships.

ii. description of the target cohort / sample:

The research is planned to take place in three secondary schools in China. The sample in this research will be the 8th grade physics classes and relevant teachers and students.
My choice of the teachers is based on two criteria: (a) I familiar with the teachers. This means that I know his or her teaching background and understand the information he or she tend to give through the interview; (b) the school where the teacher taught is easy to reach, I can easily complete face to face communication before, during or after the research project.
My choice of the lessons is based on two criteria: (a) the content of teaching, the content which is important in science curriculum in China, and (b) the willingness of video owner to participate in this type of research endeavour. Insofar as my interest is to collect data on classroom interaction, including the use of gestures and other nonverbal resources during teaching, the subject matter of the lessons did not constitute a primary criterion for selecting them. However, because of my background in physics, I decide to collect data in a physics course, if possible.

iii. methods and procedure of data collection,

Classroom observation:
The teacher will set a video recorder at the back of the classroom during his or her teaching in order to record the whole view of classroom teaching. Then, the videotapes will be sent to me directly through my personal email.
Test:
The cope of students' daily and weekly tests will also sent to me directly through my personal email.
Interview:
I will hold a semi-structured interview with participators (teachers) through Skype before and after their teaching. This interview will also be recorded with the consent of participators.

iv. data management,

The data will be properly maintained and stored during and after the research project by researcher with the consent of participators. Participants in the research have the right to withdraw their data and decide to quit the project.

v. reporting strategies,

Collected data will be reported in dissertation with further analysis. The situation of the schools and class of the participants' will be reported with the consent of participators. The situation will not include any information which make it possible to identify the schools and participants, for example the schools' name and address. The schools and participants will be given pseudonyms in the final report. Also, participants in the research have the rights to withdraw their data and decide to quit the project.

b. Outline of the interview schedule / survey / questionnaire / observation protocol or other data collection tools (if applicable depending on the methodology you plan to employ);

Table 1 Teacher Interview Schedule

Before teaching	What is your intended teaching effect today?

	What is the important and incomprehensible aspect of the concept within the teaching topic? How will you deal with the importance and incomprehension? What adjustment for the particular students will you do in the teaching design?
After teaching	How do you feel of your teaching? Are there any conflicts with your teaching design? How do you cope with the conflicts?

Table 2 Student Interview Schedule

What do you want to learn before class?
Do have any understand of the concept before class?
What do you think when you respond "…"?
How do you understand the concept-"…" now?

The questions above are just the general questions. In the interview, each question will focus on the specific teaching content – the concept which is taught in the class and try to avoid the evaluation of individual person. The data analysis and reporting will not involve the information of the evaluation of individual person. All the schools and participants will be anonymous in the report.

Appendix 1.2: Confirmation Letter of Ethics Approval

Durham University
School of Education

Shaped by the past, creating the future

26/09/2017

Yang Song
yang.song@durham.ac.uk

Dear Yang

How do teachers make meaning in science class in China? An analysis of Chinese classroom teaching under the newest curriculum

I am pleased to inform you that your ethics application for the above research project has been approved by the School of Education Ethics Committee.

May we take this opportunity to wish you good luck with your research.

Yours sincerely,

Nadin Beckmann

Dr Nadin Beckmann
School of Education Ethics Committee Chair

Leazes Road
Durham, DH1 1TA
Telephone +44 (0)191 334 2000 Fax +44 (0)191 334 8311
www.durham.ac.uk/education

Appendix 1.3: Participant Information Sheet

Title: How do teachers make meaning in science class in China? An analysis of Chinese classroom teaching under the newest curriculum

You are invited to take part in a research study of ‘How do teachers make meaning in science class in China? An analysis of Chinese classroom teaching under the newest curriculum’. Please read this form carefully and ask any questions you may have before agreeing to be in the study.

The study is conducted by Yang Song as part of her PhD research project at Durham University.

* This research project is supervised by Dr. Vanessa Kind (email at vanessa.kind@durham.ac.uk) from the School of Education at Durham University.

The purpose of this study is to analyse how teachers make meaning in science classroom through discourse analysis and try to find their theoretical explanations and interrelationships.

If you agree to be in this study, you will be asked to: (a) record your class teaching; (b) share the daily and weekly tests results of students with researcher; (c) be interviewed and asked some questions relevant to your teaching.

Your participation in this study will take approximately one semester.

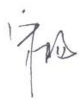
You are free to decide whether or not to participate. If you decide to participate, you are free to withdraw at any time without any negative consequences for you.

All responses you give or other data collected will be kept confidential. The records of this study will be kept secure and private. All files containing any information you give are password protected. In any research report that may be published, no information will be included that will make it possible to identify you individually. There will be no way to connect your name to your responses at any time during or after the study.

If you have any questions, requests or concerns regarding this research, please contact me via email at Yang Song, yang.song@durham.ac.uk or by telephone at 07746352821.

This study has been reviewed and approved by the School of Education Ethics Sub-Committee at Durham University (date of approval: 26/09/2017)

Yang Song



Appendix 1.4: Declaration of Informed Consent

- I agree to participate in this study, the purpose of which is to analyse how teachers make meaning in science classroom through discourse analysis and try to find their theoretical explanations and interrelationships.
- I have read the participant information sheet and understand the information provided.
- I have been informed that I may decline to answer any questions or withdraw from the study without penalty of any kind.
- I have been informed that data collection will involve the use of recording devices.
- I have been informed that all of my responses will be kept confidential and secure, and that I will not be identified in any report or other publication resulting from this research.
- I have been informed that the investigator will answer any questions regarding the study and its procedures. Yang Song, School of Education, Durham University can be contacted via email: yang.song@durham.ac.uk or telephone: 07746352821.
- I will be provided with a copy of this form for my records.

Any concerns about this study should be addressed to the School of Education Ethics Sub-Committee, Durham University via email to ed.ethics@durham.ac.uk.

____

Date Participant Name (please print) Participant Signature

I certify that I have presented the above information to the participant and secured his or her consent.

____

Date Signature of Investigator

Appendix 2: 'Good Lesson' Activity Documents

Appendix 2.1: Evaluation Index of 'Good Lesson'

Table A2.0.1 'Good Lesson' Activity Evaluation Index of 'Good Lesson'

Evaluation index	Weights	Description of standard	Score			
			excellent	good	general	Unsatisfactory
Instructional design	10	The analysis of textbooks and student situation is accurate and comprehensive; The teaching objectives are clear, specific, and operable, reflecting the overall requirements of key components; The treatment of key points and difficult points conform to the students' cognitive laws; The situation and activity design direct to problem-solving.	9-10	7-8	5-6	0-4
Teaching process	10	The teaching sequence is relatively complete, the process is smooth, and the structure is clear; The classroom capacity is appropriate, and the time layout is reasonable.	9-10	7-8	5-6	0-4
	10	There are various forms of teaching organisation and effective methods to guide students' autonomy, cooperation, and inquiry learning; Feedback and evaluation are timely and appropriate.	9-10	7-8	5-6	0-4
	10	Facing the whole class, focusing on differences, students have a wide range of participation; Highlighting the subjectivity of students and the interactivity of teaching.	9-10	7-8	5-6	0-4
	10	Skilled and reasonable application of information technology equipment; Apply information technology to support student learning, classroom communication and teaching evaluation.	9-10	7-8	5-6	0-4
	10	Apply digital resources to change the way teaching content is presented and help students understand, master, and apply knowledge.	9-10	7-8	5-6	0-4

Teaching effect	10	Students have a strong interest in learning, are proactive, have a high degree of participation, have a good experience in learning activities, and have an active and orderly classroom atmosphere.	9-10	7-8	5-6	0-4
	10	Complete the established teaching goals so that students at different levels can basically master the subject's knowledge.	9-10	7-8	5-6	0-4
	10	It can promote students' effective development in subject thinking, practical ability and emotional attitude.	9-10	7-8	5-6	0-4
Specifications of the videos	10	The course interface is well organised, the information is complete, and the language is standardised; The courseware usually runs, and the link is accurate; The video shooting content is complete, the picture is clear, and the sound and picture are synchronised.	9-10	7-8	5-6	0-4

Appendix 2.2: Activity Plan

1. Activity goals

To fully mobilise the enthusiasm, initiative and creativity of primary and secondary school teachers to apply information technology;

To organise and guide teachers to show courses on the National Education Resources Public Service Platform (hereinafter referred to as the national platform), the number of which has reached more than 1 million, from which 10,000 good lessons will be selected (Including 200 lessons in minority language teaching materials , specific work will be announced separately.) to be included in the national platform high-quality education resource library for teachers to learn from.

2. Scope of participation

Teachers of all grades and subjects in all primary and secondary schools (including primary schools, junior schools, nine-year consistent schools, complete middle schools, and ordinary high schools) with online and multimedia teaching conditions can participate voluntarily.

3. Activity content

(1) Organise online share course

Around with local conditions, teachers are organised to log in to the national platform the local platform had linked with the national platform within the stipulated time, using the function of share course on national platforms to implement online share course under the real-name system.

Share course scope

The textbook used by the share course should be the primary and secondary school textbooks validated by the Ministry of Education.

Comprehensive practice courses are conducted and evaluated in the form of special topics. Information technology disciplines in elementary and junior schools are included in the scope of comprehensive practice courses. Mental health education, safety education, and family education are conducted and evaluated in the thematic classification.

Share course node

The huge amount of resources generated by the event effectively improved the national basic education digital resource public service's capacity and level. Teachers are encouraged to share a course under the node without 'Provincial level good lesson' for quickly forming a series of high-quality resources. On the national platform, the node will temporarily close when the total number of Provincial level good lesson reach five lessons.

Share course content

The content of the online share course submitted by the teacher should include: a complete instructional design, slides, related resources and classroom teaching video (optional, required to participate in the 'Provincial level good lesson' collection of the Ministry of Education) after class tests (optional), etc. Teachers are encouraged to upload the classroom record. The classroom record (referring to the teaching process video) should show the entire process of classroom teaching (minimum 30 minutes), and the picture should be clear.

The share course content must conform to the current curriculum standards, reflect the integration of information technology and the nature and characteristics of disciplines, and focus on demonstrating the use of information technology to innovate teaching methods and effectively solve the problems of education and teaching.

Except for the national language and foreign language courses, other share courses should use the national language. The content submitted by the teacher must be the content produced in his teaching practice. It should not be replaced by impersonation to prevent plagiarism. The cited materials must indicate the source and the original author.

(2) Recommendation and selection of 'good lesson'

Based on online share courses, the local educational department should conduct evaluation and recommendation step by step.

Provincial recommendation

The provinces (district and city) select and recommend the 'good lesson' from the share courses submitted on the region's national platform. Further, it is necessary to improve the rules and standards for evaluation and recommendation, establish the idea of quality first, strictly control, and select the best, so that the recommended 'good lesson' has typical and exemplary significance. It is necessary to set a good political direction and adhere to the unity of ideology, science, and suitability. It is necessary to strict recommendation procedures, adhere to openness and transparency, and ensure fairness and justice.

To ensure the quality, each province (district, city) could recommend a maximum of 600' good lesson'. The same grade in the same subject in the same version of the same node can recommend one' good lesson' in principle, with the same teacher can only be recommended one 'good lesson' in principle.

Ministerial selection

The Ministry of Education will organise experts to evaluate and select the 'good lesson' recommended by the provinces (district and city) and prioritise nodes without 'good lesson' at the ministerial level. The selection results will be publicised and announced on the national platform.

After the ministerial level selection, those lessons that have not been rated as a provincial and ministerial good lesson will be gradually removed from the national platform. Schools and teachers in various places are requested to make backups as needed.

(3) Launch the application promotion

All localities should intensify the application and promotion of resources, organise the majority of primary and secondary school teachers to carry out activities – watch the 'good lesson', learn from 'good lesson', and earnestly learn from the achievement of a ministerial good lesson. In the teaching and research activities, 'good lessons' observation should be taken as an important content to promote teachers' professional development. It is necessary to increase the training intensity, include excellent cases of 'good lesson' into teacher training resources in the region, and encourage normal colleges and universities to use 'good lesson' to carry out case teaching.

4. Organization and implementation

The activities are organised and implemented by the Department of Basic Education in the Ministry of Education and the National Centre for Educational Technology. All localities should formulate specific activity plans, further improve the working mechanism, adhere to the education administrative department's leadership, give full play to the role of Educational Technology, teaching and research departments, and form a joint effort. It is necessary to improve support and incentive policies and mobilise the enthusiasm of teachers. It is necessary to listen to schools and teachers' opinions actively, adhere to the principle of voluntary participation, and do all our work carefully.

Appendix 3: Chinese Education System

The Chinese education system is divided into three years of kindergarten, five or six years of primary school, three years of secondary school, and three years of upper-secondary school, often followed by several years of higher education. Primary school education, as well as secondary school, are mandatory and are mostly funded by the government.

Chinese School System		Grade	Students' Ages
Pre-Primary Education			2 to 6-7
Nine-year compulsory education	Primary Education	1 to 6	6-7 to 12
	Secondary School	7 to 9	12 to 15
Upper-secondary School		**10 to 12**	**16 to 18**
Higher Education			19-

The school year in China typically starts in September and ends in late June or July with two semesters (September to January and March to late June or July).

During upper-secondary School, students have to decide what subjects they would like to learn in grade 10. The compulsory courses are Chinses, mathematics and English. The elective courses include physics, chemistry, biology, history, politics and geography. Students have to choose three elective courses from the six in national regulation. In some school or area, students do not have much freedom in choosing courses. There are course packages for them to choose. The course packages are determined by the school or area base on their strength subject. It means that student could not choose whatever subjects they like but select one of the set course packages.

Appendix 4: Code Scheme

Table A4.1 M1

Dimensions		Time	Comments
Content knowledge	Scientific concept	1:10-1:19	Magnetism
		7:25-12:30	Magnetic induction line: curves with direction
		12:50-12:55	Bar magnet: the field lines enter the south pole and emerge out of the north pole of the magnet.
		22:00-22:04	Current-carrying straight wire: the magnetic induction lines are concentric circles with dense inside and sparse outside
		29:03-30:09	Ampère's law, right-hand spiral rule
		32:18-35:02	The magnetic field around current-carrying solenoid is similar to a bar magnet's, and the Ampère's law applies.
	Scientific method	1:20-1:15	Hypothetical modelling and experimental evaluation
		2:36-2:52	Hypothetical modelling and experimental evaluation
		16:38-16:42	Hypothetical modelling and experimental evaluation
		18:59-19:43	Hypothetical modelling and experimental evaluation
		22:56-22:58	Hypothetical modelling
		23:30-27:45	Hypothetical modelling and experimental evaluation
		35:02-38:16	Hypothetical modelling and experimental evaluation
Knowledge of student	Learning strategies		Recall what they learned in junior high school, make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Recall and understand the basic concepts of magnetic fields, and know the applications of magnetic phenomena. Surface learning
	Misconceptions and prior knowledge	2:10-2:51	Students had learnt magnetic field in junior high school, know the magnetic field, and studied the distribution of magnetic fields with iron filings*
		3:10-4:28	Teacher Jack assumed that students would answer the magnetic needle. However, the student did not mention it. Jack added this information before the **Demonstration experiment**.
		4:56-5:41	Teacher use questions to guide students to think further and improve answers.
		15:40-16:00	U-shaped magnet, there is also a magnetic field around the current*

Dimensions		Time	Comments
		19:00-19:21	Student 1: The magnetic field around the current is similar to a bar magnet. Student 2: It is circular. Two conjectures are given. There is no comment on the first conjecture. However, Jack asked why, but no student answered it, and the teacher did not give an explanation too.
		22:55-23:05	The spatial distribution is the same as the plane distribution*
		23:55-24:05	The magnetic induction lines cannot intersect, so they will not look like a straight wire after bending*
		29:03-30:09	Ampère's law, right-hand spiral rule *
		31:00-31:23	The student answered that he could hold the wire with his hand and made several times. The teacher suggested that this was the idea of the infinitesimal, but back to the beginning, the middle is straight, which is not easy to explain with this idea.
Pedagogical knowledge	Instructional strategies	0:12-1:15	**Introduction**, video and questions are asked for students to answer. However, this problem is inductive. The magnet-like and stone-like objects that appear in the video are actually unmagnetized magnets and lodestone. The student's answer should be wrong, predictably.
		1:17-2:19	**Group experiment,** to verify that their answer is 'wrong', and then lead to the concept of the magnetic field.
		2:18-2:51	**Question**: how to study the distribution of the magnetic field around the magnet? Ask the student to answer it.
		3:02-4:28	**Classroom Discussion**, whether a magnetic needle can be used to study the magnetic field distribution or not.
		4:28-6:20	**Demonstration experiment**, Jack explain while doing it. Ask the student to describe the experimental phenomenon and guide student to improve the answer. Show the **photos** of iron filings taken through macro photography, and draw **Example**s of magnetic induction lines exhibited by iron filings in the **Demonstration experiment**.
		6:20-7:37	Directly tell that we could use magnetic needles to research directions, give the provisions of the magnetic field direction, and use the magnetic needle to draw a direction arrow on the magnetic induction line **Example**s. Give the concept and physics meaning of magnetic induction line.
		7:38-8:01	**Summary**: Method of studying magnetic field: distribution - iron filings, direction - magnetic needles.
		8:01-12:40	Demonstrate the **group experiment** equipment. **Group experiment**, to explore the distribution and direction of the magnetic field around the bar magnet.

Dimensions		Time	Comments
		12:43-14:25	Show students' experimental results and describe experimental phenomena. Put the results of the students' experiments together to form a model showing the three-dimensional distribution of the magnetic field around the bar magnet.
		14:31-15:34	Show the spatial distribution model - the beauty of symmetry
		15:40-16:21	There is also a magnetic field around the current (through question), introduce the Oersted experiment.
		16:27-18:00	Direction - magnetic needle (call back), **Demonstration experiment**, explain while doing it, and give the phenomenon.
		18:20-19:44	Distribution - iron filings (call back), ask students to **Guess** the distribution.
		19:50-22:03	**Demonstration experiment**, explain while doing it. Ask students to describe the experimental phenomenon and explain it - Concentric circles with dense inside and sparse outside.
		22:10-22:50	Direction - magnetic needle (call back), **Demonstration experiment**, explain while doing
		22:55-23:22	**Guess** the spatial distribution, show the spatial distribution model
		23:30-24:06	**Guess** how the magnetic field will change after the wire is bent? Show the spatial distribution model of curved, straight wires.
		24:14-27:45	Direction - magnetic needle, distribution - iron filings (call back), **Demonstration experiment**, explain while doing, and ask students to describe the phenomenon. **Demonstration experiment** (direction), describe the phenomenon.
		27:50-32:15	**Summary**: through the magnetic field around the straight wire and loop current summarised the relationship between the direction of current and the direction of the magnetic field - Ampère's law. **Underline**: The curved one is the direction of the four fingers, and the straight one is the direction of the thumb.
		32:18-35:02	**Demonstration experiment**, the magnetic field around the current-carrying solenoid. Ask students to describe the experimental phenomenon, which is similar to the distribution around the bar magnet
		35:02-37:40	**Guess** is there a loop current inside the bar magnet? Refer to the nature of the magnetic field, and whether the current can magnetise the metal materials.
		37:47-38:16	**Demonstration experiment**, ask a student to come up to help, experience and tell the phenomenon. Then ask the student to use the magnetised magnet to attract iron filings, and confirm that it has magnetism already.
		38:25-39:30	Modern physics research on electromagnetism, interested students can search for relative information online.

Dimensions		Time	Comments
		39:30-40:05	**Summary**: Magnetism in life, the discovery, development and application of magnetism
		40:12-40:50	Iron filings collector: In order to facilitate the collection of iron filings, set an excellent **Example** for students.
	Classroom management	0:00-0:10	The traditional classroom start method which is used to calm students down
		0:16-0:44	Videos attract students' attention and interest
		1:26-2:04	Group experiments
		4:28-4:48	**Demonstration experiment**
		5:51-5:54	Show pictures
		6:52-7:10	**Demonstration experiment**
		7:49-7:58	**Board**: exploration 1: test the distribution - iron filings; exploration 2: test the direction - magnetic needle
		8:20-8:30	PPT displays the group experiment equipment
		8:30-12:28	Walk around and guide the students to complete the experiment
		14:26-15:20	Show the three-dimensional distribution model
		16:10-16:20	**Board**: Exploration 3: Distribution of the magnetic field around the current
		16:42-18:24	**Demonstration experiment**
		23:15-23:25	Show the distribution model of the magnetic field around the current
		24:14-25:41	**Demonstration experiment**
		30:09-31:30	Activity: Ampère's law
		33:10-33:43	**Demonstration experiment**
		35:00-35:02	Show the distribution model of the magnetic field around a current-carrying solenoid
		37:04-37:30	Show the distribution model of the magnetic field around current-carrying solenoid and the current-carrying solenoid
		37:47-38:16	**Demonstration experiment**
		40:12-40:50	Iron filings collector
	Classroom discourse and interaction	0:12-1:15	A-I-R-Q-R-F-Q(whole)
		1:17-2:51	A-I-R-F
		3:13-4:19	I-R-F-Q(other)-R-F-Summary
		4:19-5:50	A-I-R-Q-R-Q-R-Q-R-G-R-F
		15:40-16:00	I-R-F-Q(other)-R-F

Dimensions		Time	Comments
		17:40-19:48	A-I-R-F-Q(other)-R-Q-R-F
		22:43-23:08	I-R-F-Q(whole)
		23:25-24:07	A-I-R-F
		25:41-26:44	A-I-R-Q-R-R-Q-R-Q-R-G-R-Q-R-Q
		27:50-30:09	I-R-Q-R-Q-R-Q(whole)-R-Q-R-Q-R-Q-R-Q-R-Q(whole)
		30:30-31:30	I-R-F-Q(whole)
		33:10-34:55	A-I-R-Q-R-Q-R-G-R-G-R-F
		35:15-35:38	I-R-Q-R-F
		37:50-38:16	A-I-R-F

*The student's answer is usually correct

Table A4.0.1 M2

Dimensions		Time	Comments
Content knowledge	Scientific concept	7:10-7:18	Magnetic field and the regulation of the magnetic field's direction
		22:39-23:10	Distribution of magnetic induction lines around bar magnets and U magnets
		34:10-34:40	The distribution of magnetic induction lines around the current-carrying straight wire, loop wire, and the solenoid, The magnetic induction lines: closed curve
	Scientific method	3:45-3:57	Physics research should start with the phenomena around.
		6:00-6:10	Use actual objects to verify invisible objects
		38:02-38:39	Converting a three-dimensional view to a plane view can change a direction into a dot or a cross to indicate it.
Knowledge of student	Learning strategies		Recall what they learned in junior high school, make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Recall and understand the basic concepts of magnetic fields, and know the applications of magnetic phenomena. Surface learning
	Misconceptions and prior knowledge	1:25-2:51	The concepts of magnetism had been learned in lower-secondary school, and also can be contacted in daily life. However, when students talk about the access card, Lily was trying to explain it as a magnetic card, but the student disagreed. (The student might not know how it works, but she thought it might relate to magnetism. The student has not seen it here. Here, Lily directly cited the principle of magnetic lock and ignore whether the tool is a key or a card. In this way, it does not directly deny the student, but can transition to the magnetic phenomenon in life.)
		5:00-5:37	Student answer that they had learnt in junior high school. Put a magnetic needle into a magnetic field. If it deflected, it means there is a magnetic field. The direction pointed by the north pole is the positive direction. Lily's response was not accurate enough, but what the student said was wrong. (There is no problem with the test tool, magnetic needle, but the north pole in the magnetic field refers to the direction of the magnetic induction line. Lily did not notice, or felt there was no time to explain.)
		7:10-7:18	The concept of the magnetic field has been learned before, so Lily has passed it here.
		7:18-10:06	The students have studied relevant content, but the on-site response is not active. Teachers' questions are instrumental, not questions for students to think about. After the student answers, Lily simply repeated it and went directly to the next question. Lily answered the question directly before the student answer it. When Lily reached the third question, Lily found that the process could not go on. Lily added the class discussion to make the atmosphere more active.

Dimensions		Time	Comments
		35:44-36:30	Students had studied the Ampère's Law, so they can directly tell the content of the Ampère's Law.
		36:43-37:00	Students had studied the Ampère's Law, so they can directly tell the content of the Ampère's Law.
Pedagogical knowledge	Instructional strategies	0:00-2:51	**Introduction**, props, the diode in the circuit lights up and makes a sound. Here, Lily let students mistakenly think it is voice control. Then Lily asked the student to say ‘light up’ and find that it is not voice control. This lesson is to explore the mystery. Ask students to list magnetism in their lives.
		2:51-4:20	**Review** the **History** of magnetism that students had learned in lower-secondary school. Introduce Oersted's experiment. **Question**: Oersted proposed that there is a magnetic field around the current and the magnet. What is a magnetic field?
		4:20-7:18	**Question**: how to check the existence of the magnetic field, how to judge the direction of the magnetic field? Ask the students to answer.
		7:18-10:38	**Question**: Have you researched the field before? How to describe the strength and direction of the electric field? Ask the students to answer, Lily adds. **Question**: How to understand the magnetic induction line? **Group discussion**. Ask the students to answer. Lily gave a standard definition. Then Lily gave the key content of this lesson: the simulated the magnetic induction lines in space.
		10:50-15:34	Exploration 1: The distribution of magnetic induction lines around the bar magnet and U magnet **Group experiment**. Ask students to talk about the phenomena and draw the magnetic induction lines of magnetic field on their study documents.
		15:34-22:39	Exploration 2: The distribution of magnetic induction lines around the U magnet Tips: 1) Iron filings simulate the distribution of magnetic induction lines, and the magnetic needle determines the direction and draws the magnetic induction lines. 2) Do not knock when spreading; do not spread when knocking. **Group experiment**. Show the results of the students' experiments and ask students to describe the phenomenon.

Dimensions		Time	Comments
		22:39-23:10	**Summary**: The distribution of magnetic induction lines around the bar magnet and U magnet, show **pictures**.
		23:10-33:40	There is a magnetic field around the current drawn from the Oersted's experiment. Exploration 3: The distribution of magnetic induction lines around the current **Group experiments**. Ask students to describe the phenomenon and draw the magnetic induction lines of the magnetic field on the study documents. Tips: Do not knock when spreading; do not spread when knocking. **Assign** tasks **Group experiment.** Show the results of students' experiments and ask students to describe the phenomenon. Lily showed works from the group who failed the experiment and emphasised the experimental operating procedures. (However, Lily did not explain why it failed. Why are the operating procedures stipulated in this way? Is there a detailed rule? Moreover, in the end, there is no correct experimental result showing the distribution of magnetic induction lines around the current-carrying straight wire. The teacher has no relevant plans.) **Assignment**: After class, groups exchange their results of magnetic field distributions.
		33:40-34:42	**Summary**: The distribution of magnetic induction lines around the current-carrying straight wire, loop wire and solenoid, show **pictures**.
		34:42-38:02	**Summary**: The law of the relationship between the current direction and magnetic field direction - the Ampère rule. Ask students to apply Ampère’s Law to explain the direction of the magnetic field and current. **Assignment**: Draw magnetic induction lines on the given model after class
		38:02-39:48	Convert the three-dimensional diagram into a plane view and draw it on the study documents. **Assign**ment: exchange the tasks between groups, complete the content of the study documents.
		39:51-40:35	Ask students to summarise what they have learned
	Classroom management	0:00-0:08	**Class begins**
		0:46-1:03	**Board**: The magnetic phenomena and magnetic field
		8:50-9:34	**Group discussion**, Active atmosphere after finding that students did not respond.
		10:25-10:38	Point out the important content: the distribution of the magnetic field
		11:55-12:21	Introduce the experiment equipment and procedures
		13:56-15:29	Ask the students to draw the magnetic induction lines, and Lily walked around

Dimensions		Time	Comments
		16:20-17:40	Introduce the experiment equipment and procedures
		21:10-22:39	Show the students' experiment results
		24:20-24:45	Introduce the experiment equipment and procedures
		30:34-33:30	Show the students' experiment results
		40:35-40:38	**Class is over**.
	Classroom discourse and interaction	1:25-2:37	I-R-F-Q(other)-R-F-Q-R-F-Q-R-F-Q(other)-R-E
		2:51-3:13	I-R-F
		4:49-5:37	I-S-G-R-F-Q(other)-S
		7:18-8:50	I-R-F-Q(whole)-S-Q(other)-R-F-Q-R-F-Q(whole)-S-G-Q(whole)-S
		9:34-10:06	I-R-E
		13:10-13:56	A-I-R-F-Q-R-G-R-G-R-G-Q(whole)-R
		21:48-22:39	A-I-R-G-R-G-R
		31:05-31:23	A-I-R-F
		32:00-32:30	A-I-R-G-R-F
		35:40-36:14	I-R-Q(whole)-F
		36:14-37:04	I-S-G-R-F
		39:51-40:30	I-R-E

Table A4.0.2 M3

Dimensions		Time	Comments
Content knowledge	Scientific concept	2:31-7:15	Magnetism, magnetic poles and the law of the interaction among magnets, and compared with current
		17:02-17:10	Magnetic effect of current
		31:36-32:42	The magnetic field has a force effect on the magnet and the current placed in it
		34:58-35:51	The magnetic field exists objectively around the magnet, and it has a force effect on the magnet and the current placed in it. The magnetic field has energy. The magnetic field is a unique substance that exists objectively around the magnet.
	Scientific method	6:45-7:15	Analogy, comparing electricity and magnetism
		8:10-8:15	Physics is an experimental subject, and experiments are needed to verify conjectures
Knowledge of student	Learning strategies		Recall what they learned in junior high school, make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Recall and understand the basic concepts of magnetic fields, and know the applications of magnetic phenomena. Surface learning
	Misconceptions	2:49-2:55	Students have learnt the basic electromagnetics knowledge in junior high school

Dimensions		Time	Comments
	and prior knowledge	3:00-3:53	The first student to answer this question may not understand the question. However, teacher Sophia did not change the question but only asked the same question repeatedly. After asking the same question for five times, the standard answer was still not obtained. Sophia asked another student who shows that Sophia did not anticipate that the student would answer incorrectly, and did not make corresponding changes. Sophia was very fluent in the language, and the process seemed to be very smooth. However, this was the result of the practice (interview). From this question, it could be seen that Sophia just repeated her classroom teaching over and over again, and did not think seriously. She might not reflect on the meaning of the teaching process and the solutions to possible problems. This teacher training method might quickly pay off and seem to be able to reach a decent level. However, they cannot guarantee 'quality'. What is trained is not a teacher, but a teaching machine, which can only repeat pre-set questions. It requires thinking about the difference between teachers and teaching machines? In the Chinese educational environment, what knowledge is worth teaching may not be determined by the teacher, but how to teach is presented by the teacher. It is a problem that the teacher needs to think about. However, returning to the background of recording lessons, the significance of this activity is to allow teachers to face a classroom that is different from the previous familiar ones, to test their rigorous language and on-the-spot adaptability. It is also the purpose of lesson study, while the prerequisite for achieving this goal still requires teachers to reflect.
		4:01-4:14	'I just saw you laughing. What do you think?' On the one hand, this sentence satirizes the former student, saying that he was laughed at by his classmate. On the other hand, it also said that the student laughed at others should know the answer. Otherwise, there is no right to laugh at others.
		9:50-10:05	They have learned the Oersted's experiment in lower-secondary school
Pedagogical knowledge	Instructional strategies	0:30-2:30	**Introduction**: **Demonstration experiment** (Gaussian gun), using a projector to show the experiment process. Sophia explains as she does.
		2:31-7:15	**Review** the learned knowledge in lower-secondary school: What substances can magnets attract? Is the magnetism of each area of the magnet the same? What is the law of the interaction between the two magnets? Compare with the law of interaction among charges.

Dimensions		Time	Comments
		7:15-17:32	**History**: Is there a connection between magnetism and electricity? Introduce the experimental equipment of the Oersted's experiment and discuss the experimental procedures in groups. Ask students to answer the discussion results. **Group experiment**, ask students to talk about the results of the experiment. Based on phenomena, combined with the demonstration that bar magnet can also make the magnetic needles deflect, Sophia drew that the current can generate magnetism and the magnetic effect of current, and gave the **physics history** content of Oersted's experiment.
		17:32-18:02	**Summary**: The magnet has a force effect on the magnet, and the current has a force effect on the magnet, which lead to that magnets have a force effect on the current.
		18:02-23:58	Verify the force effect of the magnet on the current. **Group discussion**, to design experiments based on existing equipment. **Group experiment**. Ask the students to tell the experiment method, and Sophia gives a summary of the experiment method. Ask students to describe the phenomenon.
		23:58-25:50	**Guess**: There is also a force effect between current and current. **Demonstration experiment** Ask students to describe the phenomenon
		25:50-30:45	**Group discussion**: The similarities between the four groups of phenomena when the interaction occurs. Ask the students to answer. They do not need to touch each other to get the force, and they interact through magnetic fields. **Group discussion**: How is the magnetic field generated? Guide the students to find that the magnetic field is generated by current and magnets **Group discussion**: How to check the existence of a magnetic field? Ask the students to answer. The magnetic needle is forced in the magnetic field, which can sense the existence of the magnetic field. **Demonstration experiment** to demonstrate the force effect of the magnetic field generated by the bar magnet on the surrounding magnetic needles.
		30:48-31:36	**Question**: how to perceive the existence of the geomagnetic field? Students answer the compass. **Lecture**: some of the animals can perceive the existence of a magnetic field.

Dimensions		Time	Comments
		31:36-34:58	**Summary**: The magnetic field has a force effect on the magnet placed in it, and the magnetic field also has a force effect on the current placed in it. **Application**: Gauss gun **Demonstration experiment**, **Group discussion**, how to use the knowledge of this lesson to explain the principle of Gauss gun. Ask students to explain, and Sophia concluded that the experiment shows that the magnetic field has energy.
		34:58-35:51	**Summary**: The magnetic field exists objectively around the magnet, and it has a force effect on the magnet and current placed in it. The magnetic field has energy. It is concluded that the magnetic field is a special substance objectively existing around the magnet (matter: powerful and energetic, special: invisible and intangible).
		35:51-39:16	**Application** of magnetic field: **Demonstration experiment**, electromagnetic gun **Picture**: maglev train **Demonstration experiment**, cathode ray tube **Picture**: cyclotron, tokamak magnetic confinement device, an alpha magnetic spectrometer **Assignment**: Looking for applications related to magnetism in life
		39:16-40:27	**History**: The knowledge of magnetism in ancient China was the first to discover the phenomenon of magnetism, and it was recorded and used in navigation. However, in modern times, we have fallen behind, we need to catch up, and it depends on the efforts of all of us.
		40:27-40:59	**Summary**: Current and magnet can generate magnetism, the field is substance. Magnetism and electricity can interact, Magnetism and electricity can be transferred. There is physics everywhere in life which just need us to pay attention to. I use my mind to understand physics, Learn to use and travel around the world.
	Classroom management	0:00-0:05	**Class begins**
		2:13-2:30	**Board**: The magnetic phenomena and magnetic field
		8:16-8:25	Introduce the experiment equipment and **Assign** discussion tasks
		10:23-10:49	Introduce the experimental considerations
		18:02-18:10	Introduce the experiment equipment and **Assign** discussion tasks
		21:40-21:45	Introduce the experiment procedure based on the student's answer
		28:02-28:14	**Board**: the magnetic field is generated by the magnet and current
		29:14-29:30	**Board**: magnetic needle
		29:34-29:44	Introduce the experiment equipment

Dimensions		Time	Comments
		32:30-32:33	**Board**: current
		41:00-41:07	**Class is over**.
	Classroom discourse and interaction	2:45-2:56	I-R-Q-R-E
		2:57-4:45	I-R-Q-R-Q-R-Q-R-Q-R-Q(other)-R-Q-R-Q-R-Q-R-F
		4:45-5:35	I-R-Q-R-Q-R-F
		6:00-6:45	I-S-G-R-Q-R-F
		9:45-10:09	I-R-Q-R-F-Q(whole)
		14:55-15:30	A-I-R-Q-R-Q(whole)-F
		15:35-16:29	I-S-G-Q-R-Q-R-F
		21:00-21:45	A-I-R-F
		22:55-23:30	A-I-R-G-Q-R-F
		23:58-24:22	I-S-G-R-E
		24:55-25:03	A-I-R-F
		25:42-25:50	A-I-R-F
		26:25-26:35	I-A-Q-R-E
		27:18-27:58	I-G-Q-R-Q-R-Q-R-Q-R-F whole classroom question and answer
		28:30-29:14	I-S-Q-R-G-R-F
		30:30-30:40	A-I-R-E
		31:05-31:22	I-R-E
		33:16-34:00	A-I-R-Q-R-Q-R-G-R-F
		37:20-37:38	A-I-R-Q-R-F

Table A4.0.3 M4

Dimensions		Time	Comments
Content knowledge	Scientific concept	3:50-5:03	Magnetism, magnet, magnetic poles and the law of the interaction among magnets, and charges
		13:59-14:15	Magnetic effect of current
		27:40-27:50	The definition and properties of the magnetic field
		31:04-31:25	The concept of the geomagnetic field
	Scientific method	4:40-5:01	Analogy, comparing electricity and magnetism
		27:00-27:33	Analogy, charges interact with each other through an electric field, leading to the concept of a magnetic field
Knowledge of student	Learning strategies		Recall what they learned in junior high school, make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Recall and understand the basic concepts of magnetic fields, and know the applications of magnetic phenomena. Surface learning
	Misconceptions and prior knowledge	1:35-2:10	Some students have seen the magic
		4:40-4:50	Students have learnt the relevant knowledge
		5:38-5:41	Students have learnt the relevant knowledge
		6:45-7:50	Students have learnt the relevant knowledge
		21:18-21:44	Students have learnt the relevant knowledge
		29:03-29:14	Students have learnt the relevant knowledge
		30:34-30:44	Students have learnt the relevant knowledge
Pedagogical knowledge	Instructional strategies	0:10-3:07	**Introduction**: magic show, and facilitated by video to make students see more clearly
		3:32-5:03	**Demonstrate** the bar magnet can attract the metal pin. **Review** the relevant knowledge and compare with the interaction among charges.
		5:05-13:45	Question: Is there any connection between electricity and magnetism? **Group discussion**, ask students to talk about relationships. **Group discussion**, how to verify the relationship. **Group experiment**, students are invited to come up to demonstrate and explain the experimental process and results.
		13:59-18:43	**History**: The discovery process of Oersted's experiment was obtained after years of research. **Question**: Oersted’s experiment proved the effect of current-carrying wires on magnets, combined with Newton’s third law, does the magnet also have a force effect on current-carrying wires? **Demonstration experiment**, explain while doing. Repeat it twice, and it can be observed that the magnet exerts a force on the current-carrying coil.

Dimensions		Time	Comments
		18:43-19:45	**Application**: Electromagnetic catapults for aircraft. Currently, only the United States has electromagnetic catapults. Other countries are still developing them. China is also in the research and development stage. Leo also hoped that students could participate in the development of Chinese aircraft electromagnetic catapults in the future and win glory for the motherland and the school (patriotism education).
		19:45-26:35	**Summary**: There is an interaction between magnet and magnet, current and magnet. **Question**: Is there any interaction between currents? **Group discussion**, ask students to answer, and Leo gives out that there is an interaction between current and current. Show a **picture**, the support of high-voltage power lines. **Question**: What is the role of the support? **Demonstration experiment**, explain while doing it. Repeat twice. Ask students to describe the phenomenon and Leo explains the purpose of the support is to separate two wires that pass current in the same direction. **Question**: On this basis, what happens if a reverse current is applied? **Demonstration experiment**, explain while doing it. Repeat twice. There is also an interaction between the current and the current.
		26:35-27:40	**Question**: The interaction between the magnets, between the magnet and the current, between the current and the current, does not need to contact, so how do they interact? Review the knowledge of the electric field, which lead to the concept of the magnetic field.
		27:40-28:06	Give the definition and basic properties of the magnetic field. **Exercise**: Use the magnetic field to explain the interaction between two magnets. **Question**: How does the interaction between two current-carrying wires occur? Ask the students to answer, and Leo makes a **Summary**.
		29:38-31:04	**History**: Introduce related research in ancient China. Sinan, the originator of the compass (patriotism education). **Question**: Why can the compass set the direction? Introduce the geomagnetic field.
		31:04-37:14	**Application**: Introduce the concept and function of the geomagnetic field, and play a video to show the function of the geomagnetic field. Then, Leo introduces the frontier knowledge of physics - magnetic monopole and invites a student to read it aloud. Leo explains that it has not been discovered so far and hopes that students could be interested in conducting research, and the Nobel Prize in Physics will be waiting for the students.

Dimensions		Time	Comments
		37:14-38:28	Introduce the content of the next lesson: judging the direction of the magnetic field by the magnetic needle. **Assignment**: Thinking about how to use existing experimental equipment to determine the direction of the magnetic field. **Summary**: magnetic phenomena, magnetic effects of current, definition and basic properties of the magnetic field, geomagnetic field. **Assignment**: Discover the magnetic phenomenon and the application of magnetic phenomenon in life, read the content of the book, page 82
	Classroom management	0:00-0:10	**Class begins**
		3:07-3:32	**Board**: The magnetic phenomena and magnetic field
		4:45-5:03	Show the comparison table of electrical and magnetic phenomena, and give students time to take notes
		5:05-5:11	**Assign** discussion tasks
		5:55-6:06	**Assign** discussion tasks
		8:05-8:45	Introduce the experiment equipment and considerations
		16:09-16:30	Introduce the experiment equipment
		19:45-20:30	**Board**: magnet ⟷ magnet ↕ ↕ current current
		20:38-20:42	**Assign** discussion tasks
		22:37-22:58	Introduce the experiment equipment
		25:35-25:41	Introduce the experiment circuit diagram
		27:40-27:44	**Board**: magnetic field
		27:50-28:05	Props: Bar magnet
		31:03-31:10	**Board**: Geomagnetic field
		38:28-38:36	**Class is over**.
	Classroom discourse and interaction	1:35-2:10	A-I-R-Q-R-E
		4:40-4:48	I-R-E
		5:29-5:55	A-I-R-F
		6:43-8:03	A-I-R-Q(other)-R-Q-R-G-Q(whole)-R-Q-R-F

Dimensions		Time	Comments
		10:00-12:10	A-I-R-Q(whole)-(clapping hands)-E(**Demonstration experiment** was done by students)
		12:12-13:21	A-I-R-E- (clapping hands) (**Demonstration experiment** was done by students)
		21:03-21:56	A-I-R-F-Q(other)-R-F
		24:20-24:30	A-I-R-F-Q(whole)-R
		28:59-29:29	I-R-F
		30:30-30:59	A-I-R-E

Table A4.0.4 M5

Dimensions		Time	Comments
Content knowledge	Scientific concept	1:50-3:30	Magnetism, magnet, magnetic pole, magnetisation, demagnetization
		5:47-9:28	The concept and properties of the magnetic field
		14:14-14:38	The direction of the magnetic field - the direction that the north pole of the magnetic needle point to
		14:50-17:00	The magnetic induction lines
		24:34-25:00	Ampère's law
		40:12-40:51	Geomagnetic field
	Scientific method	0:38-0:45	Analogy, with the electric field
		11:25-11:30	Analogy, with the electric field
		15:50-15:54	Analogy, with the electric field
		34:40-34:45	Analogy, with the magnetic field around the bar magnet
Knowledge of student	Learning strategies		Recall the content learned in junior high school, summarise the concept and law, and apply knowledge to solve problems. Deep learning
	Misconceptions and prior knowledge	5:03-5:06	Students have learnt the basic electromagnetics knowledge in junior high school
		6:20-6:24	A student answers 'Faraday', Oliver repeated 'Faraday? ! Hum' expressed
		13:10-13:15	A bit of contempt. It seems an incredible answer for Oliver. Oliver assumes that students will answer correctly. Then, Oliver explained that Faraday found that magnetism could generate electricity, while the fact that electricity generating magnetism is found by Oersted.
Pedagogical knowledge	Instructional strategies	0:38-1:28	Analogy to the content of the electric field Complicate simple things: There are two forces involved, Ampère force and Lorentz force. However, this expression is problematic. These are not two forces, but the 'Ampère force' is deduced from Lorentz force. Complicate simple things: learning this lesson could know how to use the two hands. However, the use of two hands is actually one principle. Here, Oliver says that the content of this lesson is very complicated so that students would listen carefully, but it will also increase the psychological burden of students' learning. What is drawn from this is how to make students listen carefully? Use a joking tone to link knowledge with the exam to emphasise the importance of this lesson.
		1:35-3:30	**Review** the knowledge learned in lower-secondary school. Oliver points out the points (the focus of the exam) that need attention.
		3:30-4:28	**History**: Magnetic phenomena, the application of magnetism in ancient China

Dimensions		Time	Comments
		4:28-11:00	**Lecture**: Magnetic field, the important knowledge point. Compare with the electric field. The interaction between magnets is based on the magnetic field. (There is no emphasis on the simultaneity of the interaction, which will cause students to think that one magnet generates a magnetic field acting on another one, then the other magnet generate a magnetic field and reaction on the first magnet. At the same time, the metaphor here is also misleading. It separates the magnetic field and the magnet into two different individuals to make the metaphor—a pair of blind daters and a matchmaker.) **Lecture**: There is a magnetic field around magnets and currents, Oersted's experiment. **Note**: There is a magnetic field in the space around the current, and the current is formed by a large number of moving charges. Therefore, there is also a magnetic field in the space around the moving charge, and there is no magnetic field in the space around the static charge. Repeat three times and give students time to take notes. **Lecture**: Definition and properties of the magnetic field **Lecture**: The magnetic field has a magnetic effect on the magnet current. There are also interactions between currents. Same direction attraction, reverse repulsion.
		11:00-14:50	Show the **schematic diagram** to show the presence of a magnetic field. **Analogy**, the electric field. Show the **schematic diagram**, the direction of the magnetic field. Oliver emphasised that there are two regulations, but the two regulations look similar. One is the direction pointed by the N pole of the magnetic needle; the other is the direction of the force on the north pole of the magnetic needle. Emphasise the direction of the force in order to be related to the Ampère force in the next lesson.
		14:50-20:05	**Lecture**: Give the concept of electric field lines. Show a simulation diagram of the magnetic induction line a U magnet. **Lecture**: Define the magnetic induction line and its physics meaning. **Emphasis**: it is an imaginary curve, invisible and intangible **Lecture**: Analogy with electric field lines, give the direction and characteristics of magnetic induction lines. There is a problem here. If the magnet is hollowed out, the magnetic induction line would be different, so this statement is not accurate. The inside of the magnet refers to the inside of the entity, not the 'inside'.

Dimensions		Time	Comments
		20:05-35:50	**Lecture**: Determination of the direction of the magnetic field. Show the simulation **diagram**s and schematic diagrams of a bar magnet and a U magnet. Oliver emphasis that it is a uniform magnetic field in the middle area of the U magnet (except the edges), repeat three times. **Lecture**: Ampère’s law is given to determine the direction of the magnetic field around the current. Show the simulation **diagram** and schematic diagram of the magnetic field around the current-carrying straight wire, demonstrate activities, prompt students to distinguish between left and right hands. **Lecture**: Give the drawing specification, the direction represented by the dot and the cross. Practice drawing top and side views. Show the simulation **diagram** and schematic diagram of the magnetic field around ring current, and demonstrate the activity. Oliver asks students to pay attention to the magnetic field direction on the central axis. Practice drawing top and side views. Show the simulation **diagram** and schematic diagram of the magnetic field around the current-carrying solenoid, and demonstrate the activity. Practice drawing top and side views. Analogous to the distribution of magnetic induction lines of a bar magnet.
		35:50-36:27	The difference between electric field lines and magnetic induction lines is whether they are closed or not.
		36:27-40:12	**Lecture**: Based on the **Example** of Oersted’s experiment, the direction of the magnetic field is used to determine the direction of charge movement. **Question**: How about changing the deflection direction of the magnetic needle in the **Example**?
		40:12-41:51	**Lecture**: Geomagnetic field, geographic north and south poles. Give an **Example**
		41:51-41:54	**Assignment**
	Classroom management	0:00-0:07	**Class begins**
		0:07-0:16	Ask students' to turn to page 80
		1:25-1:35	After calling to stand up, stop talking. Turn to page 80 and take the notebook out.
		6:23-6:24	Write it down, Oersted's experiment
		7:02-7:05	Write it down, but don’t write it now, let’s take a look first.
		9:28-9:35	Write it in your notebook
		14:50-17:12	Write it in your notebook
		21:45-21:55	Write it in your notebook
		23:45-23:47	Take out your right hand and apply Ampère’s rule

Dimensions		Time	Comments
		26:03-26:06	Put the fourth picture in the notebook
		30:16-30:18	Are you finished? Hurry up
		34:10-34:13	Hold the book and stand behind for a while (student is sleepy)
		35:05-35:50	Give student enough time to take notes
		37:45-37:48	You also need to stand for a while
		41:54-42:03	**Class is over**
	Classroom discourse and interaction	5:03-5:06	I-R-F(whole classroom interaction)
		6:20-6:24	I-R-F (whole classroom interaction)
		13:10-14:05	I-S-R(whole classroom interaction)
		18:20-18:40	A-I-R-Q-R-F(whole classroom interaction)
		37:00-40:12	A-I-R-Q-R-Q-R-Q-R-Q-R-Q-R-G-Q-R-Q-R-R-Q-G-Q-R-Q-G-Q-R-Q-R-Q-G-R-Q-R
		41:02-41:51	A-I-R-G-Q-R-Q-R-G-Q-R

Table A4.0.5 F1

Dimensions		Time	Comments
Content knowledge	Scientific concept	3:32-3:34	The definition of Ampère force
		35:10-35:12	F=BIL
		39:15-39:40	The left-hand rule
	Scientific method	4:33-7:49	Hypothetical modelling and experimental evaluation Control Variable method
Knowledge of student	Learning strategies		Make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Apply and verify the conclusions. Deep learning.
	Misconceptions and prior knowledge	1:08-1:14	Learned knowledge
		1:38-1:56	Learned knowledge
		5:31-5:50	There is related content in the book, but the magnetic induction intensity, B, was not studied, so the student did not refer to it. The student suggested that it might be related to the wire material, and Charlie explained it, but the explanation was not accurate. Charlie asked that whether the material is the resistance of the conductor. Then, Charlie pointed out that the resistance is constant, so it is irrelated with it. The material equals the resistance of the conductor is wrong. The second student answered that it is related to the magnetic field, and Charlie guided to say the strength of the magnetic field. It is not a real hypothesis and experiment process; a hypothesis should be verified by experiments, rather than empty words.
Pedagogical knowledge	Instructional strategies	0:08-3:47	**Review** the content of the last class, and the magnetic phenomenon is a magnetic field (but the arrangement of the textbook is the magnetic induction intensity before this). **Group experiments**, to experience the effect of magnets on current. Ask students to talk about experimental phenomena. Charlie read aloud the text about the naming of Ampère force.
		4:33-7:49	Give directly, the force has magnitude and direction, then how to study the magnitude and direction of Ampère force? What are the factors? **Group discussion**, ask students to tell the results of the discussion. Charlie responded and summarized three influencing factors. The conclusion can be gotten through communication that uses the variable control method to conduct experimental research.

Dimensions		Time	Comments
		7:49-15:00	**Demonstration experiment**, introduce experimental equipment and principles and explain while doing it. (But the experiment is not rigorous. Charlie manually rotates the U magnet, and the angle cannot be measured, and no quantitative results can be obtained.) **Question**: In the process of rotating the U-shaped magnet, the force changes. What factors are related to the Ampère force? (This question is problematic. The Ampère force is not related to the angle, but the effective length of the wire.) Ask the students to answer. The direction answered by one student, which is not accurate, and Charlie directly asked the other student to answer. Here, Charlie did not explain. **Question**: When did the maximum and minimum values of Ampère force appear? Since the experiment is not quantitative, this question is a bit difficult. The student answered incorrectly. No explanation was given, but the **Demonstration experiment** was repeated, and the experimental results were directly given.
		15:42-35:35	Since Charlie put the magnetic induction intensity into the next class, this lesson only involves the relationship between force and the other two factors when the magnetic induction intensity stays the same. **Demonstration experiment**, introduce experimental equipment and principles and explain while doing it. Ask students to record data on their study documents. When the current is constant, change the length of the wire, students record and make the graph, show the results of one student, point out the student's problems, and ask another student to show the results. When the current is constant, the force is proportional to the length of the wire. When the length of the wire is unchanged, adjust the current, and the students record and make the graph, show the student's results. When the wire length is fixed, the Ampère force is proportional to the current intensity. **Question**: Can we conclude that F=IL? Students could not answer it because the magnetic field has not been studied yet. The teacher goes back to the experimental conditions, the magnetic field intensity does not change, and directly gives the formula F=BIL for Ampère force, when the magnetic field intensity is constant, and the wire is perpendicular to the magnetic field. It is not scientific, it is related to B, but whether it is proportional or not, we still need to do experimental verification.
		35:38-40:29	**Demonstration experiment**. Determine the direction of Ampère force and explain as doing it. Give the result from Charlie's angle without doing another experiment. The table showed four directions. Give the left-hand rule, and use the left-hand rule to determine whether the direction in the table is consistent.
		40:30-40:42	**Summary**: This lesson has learned the magnitude of Ampère force in two specific situations, and how to judge the direction of Ampère force with the left-hand rule. **Assignment**.

Dimensions		Time	Comments
	Classroom management	0:00-0:08	**Class begins**
		2:08-2:32	Introducing the group experiment equipment
		3:10-3:12	Guys, please be active, OK?
		3:26-3:28	Turn to page 86, the second paragraph.
		3:47-4:30	**Board**: the force on the current-carrying wire in the magnetic field
		4:38-4:52	**Assign** discussion tasks
		7:06-7:22	**Board**: 3 factors, the magnetic field strength, the current and the length of the wire
		7:40-7:49	**Board**: variable control
		8:00-10:30	Introduce the experiment equipment and principles **Board**: The sign in the display indicates the direction of the force.
		15:00-15:34	**Board**: When the wire parallel to the magnetic field, F=0. When the wire perpendicular to the magnetic field, F max.
		16:25-17:20	Introduce the experiment equipment and principles
		18:45-18:47	Ask students to record the experimental phenomena
		22:43-22:53	Ask students to record and plot the data
		28:10-28:28	**Board**: the current is constant, $F \propto L$; the length is constant,
		31:10-31:19	Ask students to record and plot the data
		33:46-33:59	**Board**: $F \propto I$, $F \propto IL$
		35:37-35:40	**Board**: direction
		39:23-40:28	Activity, use the left-hand rule to determine the direction
		40:42-40:47	**Class is over**.
	Classroom discourse and interaction	0:32-1:14	I-S-Q-R-E(OK, sit down please.)
		1:35-1:57	I-R-E(Perfect, sit down please.)
		3:07-3:21	I-S-Push-R-F(whole classroom interaction)
		5:28-7:06	A-I-R-Q-R-F-Q-R-Q-R-G-Q-R-Q(other)-R-Q-R-Q-R-E(OK)
		7:35-7:40	I-R-E(Perfect) (whole classroom interaction)
		12:28-13:10	A-I-R-Q(other)-R-Q(whole)-R
		13:20-14:04	I-G-R-Q-R-F
		27:20-28:10	A-I-R-G-Q-R-Q-R-E(OK)
		34:00-34:45	I-R-E(OK, sit down please.)

Table A4.0.6 F2

Dimensions		Time	Comments
Content knowledge	Scientific concept	3:26-3:38	Ampère force, the force on the current-carrying wire in the magnetic field
		13:30-13:59	Left-hand rule
		37:30-37:33	F=BIL
	Scientific method	5:00-5:43	Hypothetical modelling and experimental evaluation
		24:45-24:50	Control Variable method
		36:43-36:53	The process of physics inquiry should be: asking a question, making a hypothesis, designing an experimental investigation, establishing law, drawing and sharing conclusion.
Knowledge of student	Learning strategies		Make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Apply and verify the conclusions. Deep learning.
	Misconceptions and prior knowledge	12:35-13:30	Learned knowledge
Pedagogical knowledge	Instructional strategies	0:10-2:20	**Props**, ask students to explain the phenomena, then Ji gave the explanation. Ji introduced the principle of the experiment and said it is the power of knowledge!
		3:35-14:45	Introduce the experiment equipment and principles, **Question**, what are the factors that related to the direction of Ampère force? Current and magnetic field. **Assign** tasks, **Group experiment**. Ask a student to give the results. Observe the model done by students and induct spatial relationship, left-hand rule. Ji said it is to show respect to the predecessors. (But this left-hand rule was not invented by the predecessors. The official left-hand rule is Fleming's left-hand rule.) Ji said the past is theirs, and the future must be the students', to encourage students.
		14:45-17:21	Play the electromagnetic railgun **video** and show the schematic **diagram** of the electromagnetic railgun. Apply the left-hand rule, **activity**. Ji told that students that to increase the power of the electromagnetic railgun is to increase its Ampère force.

Dimensions		Time	Comments
		17:21-38:42	**Question**: Factors that are affecting the magnitude of Ampère force. Ask students to answer and conclude that the magnitude of the Ampère force is related to the current, the length of the current-carrying wire in the magnetic field, and the magnitude of the magnetic field strength. Since the students had not learned the concept of magnetic field strength, Ji suggested that this lesson only explore the relationship between Ampère force and current and length. Introduce experimental equipment and **Group discussion**. Ask students to answer the discussion results and get the experimental plan. **Assign** experimental tasks and **group experiment**. Ask students to show the results of the experiment, explain and summarize. **Summary**: Ji summarizes the inquiry process and experimental conclusions, F=kIL. **Question**: What does k relate to? **Lecture**: k is B, the physics quantity that reflects the intensity of the magnetic field. F=BIL, (I⊥B)
		38:42-41:39	**Assignment**: If the current is not perpendicular to the magnetic field. Does the left-hand rule still apply? What will the Ampère force formula be? Find out the application of Ampère force in life. **Summary**: Ask students to summarise, the direction of Ampère force is determined by the left-hand rule. The calculation formula of Ampère force, F=BIL. The application of Ampère force in life. The physics experiment process is cumbersome and requires cooperation. Ji's **summary**: The concept of Ampère force, the left-hand rule, and the formula for calculating Ampère force through scientific methods.
	Classroom management	0:00-0:10	**Class begins**
		2:20-3:26	Turn to page 84 **Board**: the force on the current-carrying wire in the magnetic field
		3:46-3:50	Introduce experimental equipment
		5:39-6:28	**Assign** experimental tasks of each group
		10:15-10:25	Ask students to hold up the models they made and observe them
		10:48-11:28	**Board**: the direction of Ampère force, F⊥B, F⊥I, I⊥B Hold up the models again, rotate them and observe them
		16:33-16:35	Hold left hand up, apply the left-hand rule to determine the direction of Ampère force that experienced by the railgun.
		18:42-19:23	Introduce experimental equipment and **Assign** discussion tasks
		23:28-26:10	**Assign** experimental tasks of each student

Dimensions		Time	Comments
		32:40-33:15	Ask students to show their models
		36:30-36:40	**Board**: the magnitude of Ampère force, I is constant, F∝L; L is constant, F∝I
		37:45-37:48	**Board**: F=BIL
		38:37-38:39	**Board**: (I⊥B)
		41:38-41:44	**Class is over**
	Classroom discourse and interaction	0:50-1:18	A-I-R-Q-R-E(Perfect, sit down please)
		1:50-2:04	I-R-Q-R-E(Perfect, he is good at observation)
		3:56-4:41	A-I-S-G-R-F
		4:54-5:25	I-R-Q-R-Q-R-F
		6:03-6:24	I-R-E(Perfect)
		6:35-6:56	I-R-Q-R-E(Perfect, sit down please)
		9:26-10:13	A-I-R-E(Perfect, sit down please)-Q-R-E(Correct)-Q-R-E(Perfect)-Q-R-F
		10:25-10:47	A-I-S-Q-R-E(Perfect, sit down please)
		11:30-11:55	A-I-R-Q(whole)-F
		12:35-13:59	A-I-R-Q-R-Q-R-F
		17:37-18:25	I-R-Q-R-Q-R-Q-R-Q-G-R-F
		20:50-23:18	A-I-R-Q-R-Q-R-Q-R-G-R-F-R-Q-G-R-F-G-Q(other)-R-Q-R-F
		24:24-24:50	I-R-G-Q-R-F
		25:25-25:59	I-R-Q-R-G-R-Q-R-E
		33:44-36:40	A-I-R-Q-E(Perfect, sit down please)-F-Q(other)-R-E-Q(other)-R-E-Q(other)-R-F
		37:20-37:24	I-R-F(the whole classroom interaction)
		38:00-38:37	I-R-Q-R-Q-R-F
		39:48-41:18	I-R-E-Q(other)-R-E

Table A4.0.7 F3

Dimensions		Time	Comments
Content knowledge	Scientific concept	16:56-17:01	The Ampère force direction must be perpendicular to the plane formed by the current and magnetic field.
		17:53-18:15	Left-hand rule
		33:59-34:03	F=BIL
	Scientific method	8:20-8:22	Control variable
		20:55-20:56	Control variable
Knowledge of student	Learning strategies		Make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Apply and verify the conclusions. Deep learning.
	Misconceptions and prior knowledge	7:00-7:24	The student answered the magnetic field and current, and did not refer to the length of wire.
		7:35-8:21	One student answered the experimental method; however, the standard answer in George's mind is Control variable method. George tried to guide the student and said that there are two variables. The student answered Comparative Experiment. George did not respond to the student and asked another one to answer it and got the standard answer.
		19:18-20:44	The student still answered the magnetic field and current. The other student said it might relate to the properties of wire, and George directly told the students that the property is the length without explaining.
Pedagogical knowledge	Instructional strategies	0:00-2:00	**Introduction, props**, a simple speaker
		2:48-7:00	**Demonstration experiment**, explain while doing it. (Inadequate preparation for the experiment. George spent three minutes looking for the batteries to be used in the experiment. Let the students read the textbook first.) Introduce the definition of Ampère force.

Dimensions		Time	Comments
		7:00-19:10	**Question**: In what ways could we explore Ampère force? Ask the students to answer, the magnitude and direction of the force. George proposes to explore the direction first. **Question**: Factors affecting the direction of Ampère force. The student replied, magnetic field and current. **Question**: How to explore? The experimental method, control variables Give four kinds of experimental conditions, introduce the experimental equipment, George made a **Demonstration experiment** 1-1, the students build a model based on the experimental phenomenon, and George also shows the correct appearance. George demonstrates the experiment 1-2, 1-3, 1-4, the students build models. Ask students to compare and modify. Summarize the experimental rules: the direction of Ampère force is related to the direction of the current and magnetic field **Group discussion**, the spatial relationship of direction. Ask the students to answer. **Lecture**: the Ampère force direction is perpendicular to the plane formed by the current and magnetic field. **Lecture**: the left-hand rule. Ask students to apply the left-hand rule to determine whether the model conforms.

Dimensions		Time	Comments
		19:15-34:03	**Question**: Factors that are affecting the magnitude of Ampère force. Ask students to answer and conclude that the magnitude of the Ampère force is related to the current and the magnitude of the magnetic field strength. **Lecture**: it is also related to the length of the wire. George suggested that this lesson only discuss the quantitative exploration between the Ampère force and the magnitude of the current, and the length of the wire when the direction of the current is perpendicular to the direction of the magnetic field. **Demonstration experiment**, introducing experimental equipment and principles. Moreover, let the students use the left-hand rule to determine the direction, twice. Guide student to design the experiment plan. **Demonstration experiment**, students record data. Ask two students to cooperate with the experiment (only reading and recording data, the data displayed on the big screen for students to record, the other students only copy the data). (The experiment was not fully prepared and it took two minutes to adjust the instrument). George drew the results of the experiment through the computer and asked the students to summarize the conclusion. (Here, the results of the experimental data have deviation) **Lecture**: George explained that it is within the error range and a large number of accurate experiments show that $I \perp B$, $F \propto L$, $F \propto I$, $F \propto IL$, $F=kIL$, $F= BIL$, we use B to indicate the strength of the magnetic field.
		34:04-38:59	Revisit the **Introduction** experiment, and explain while doing it, and ask students to use what they have learned to discuss the principle of sound production. **Group discussion**, ask students to answer under the guidance. **Question**: How to increase the volume? Ask the students to answer. **Lecture**: Based on the influencing factors put forward by the students, George gave a corresponding demonstration (George directly gave the method of change, and did not let the students think about it). George gave the last factor and asked the students to design and demonstrate.
		38:59-40:01	Introduce the application of the Ampère force, simple electric motor **Assignment**: Make your simple motor.
	Classroom management	2:05-2:32	**Board**: the force on the current-carrying wire in the magnetic field
		6:31-6:49	**Board**: the definition of the Ampère force
		8:43-9:59	Introduce experimental equipment **Assign** experimental tasks of each student
		11:10-14:18	Ask students to hold up the models they made and modify the wrong models Exchange the tasks and do again.

Dimensions		Time	Comments
		15:04-15:36	**Board**: the direction of Ampère force is related to the direction of magnetic field and current. **Assign** discussion tasks, **Group discussion**
		17:04-17:25	**Board**: the Ampère force direction must be perpendicular to the plane formed by the current and magnetic field.
		18:38-18:40	**Board**: left-hand rule
		20:45-21:12	The slide showed: the magnitude of the Ampère force is related to the current, the length of the current-carrying wire in the magnetic field, and the magnitude of the magnetic field strength. George suggested that this lesson only discuss the quantitative exploration between the Ampère force and the magnitude of the current, and the length of the wire when the direction of the current is perpendicular to the direction of the magnetic field.
		21:51-24:47	Introduce the experiment equipment and principles Apply the left-hand rule and give the experimental plan.
		25:00-26:12	**Assign** data recording tasks **Board**: experiment 1, explore the relation between F and L experiment 1, explore the relation between F and I Ask two students to come and assist the experiment.
		32:58-33:42	**Board**: when $I \perp B$, $F \propto L$, $F \propto I$, $F \propto IL$, $F=kIL$, $F=BIL$
		35:22-35:25	**Assign** discussion tasks, **Group discussion**
		40:01-40:06	**Class is over**.
	Classroom discourse and interaction	6:20-6:31	A-I-R-Q-R-Q-R(T)-E(the whole classroom interaction)
		7:00-7:24	I-R-F
		7:35-8:21	I-S-R-Q(other)-S-F-Q-R-Q-R-Q(other)-R-F
		14:34-15:03	A-I-S-G-R-Q-R-E-Q-R(T)(the whole classroom interaction)
		15:54-16:43	A-I-R-Q-R-E(Good, sit down please)-Q(other)-S-F
		18:58-19:10	A-I-R-F-Q(other)-F
		19:18-20:44	I-R-Q-R-Q-R-Q(other)-S-G-R-Q(other)-R-G-R-F
		23:40-24:37	A-I-R-F-Q(whole)-G-R-E(Perfect, sit down please)
		31:55-32:01	I-R-F
		35:46-36:23	A-I-R-Q-G-Q-R-G-R-G-R-E(Perfect, sit down please)
		36:34-36:57	I-R-G-R-E(Perfect, sit down please)

Dimensions		Time	Comments
		37:40-38:02	I-R-E(Perfect, sit down please)

Table A4.0.8 F4

Dimensions		Time	Comments
Content knowledge	Scientific concept	28:15-28:19	F=BIL
		36:23-36:45	Left-hand rule
	Scientific method	7:08-7:11	From general to special
		10:24-10:26	The experimental method, control variable method
		29:02-29:05	Experimental evaluation
Knowledge of student	Learning strategies		Make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Apply and verify the conclusions. Deep learning.
	Misconceptions and prior knowledge	7:52-9:00	Have not learnt the formula of the magnetic induction strength, could not know that the length is related to the Ampère force.
Pedagogical knowledge	Instructional strategies	0:04-2:10	Props, simple electric motor, Oscar give the principle and introduce the definition of Ampère force
		2:53-7:52	**Demonstration experiment** 1, to verify the force on the current-carrying wire in the magnetic field. Explain while doing it. When there is no current, the force sensor has an indicator, which is the gravity of the coil, and Oscar made the Zero adjustment. **Lecture**: The reason for the Zero adjustment and show the zero adjustment process, rigour. **Lecture**: Oscar gave the experimental phenomenon and repeated the experiment. **Lecture**: The Ampère force is related to the position of the current in the magnetic field. This lesson will study the magnitude of Ampère force when the current is perpendicular to the magnetic field. **Lecture**: The force is a vector, with magnitude and direction.
		7:52-28:19	Question: What factors are related to the magnitude of Ampère force? Ask students to answer, magnetic field and current. Oscar pointed out the length of the wire (it would be better mentioned later during or after the experiment). **Group experiment** 1, introduce the experimental equipment and principle, and circuit, and ask students to give the experimental design, Oscar summarized the experimental design, and **Assign** the experiment tasks of each group. Ask students to introduce the experimental results and summarize the conclusions.

Dimensions		Time	Comments
		28:26-36:50	Question: Factors affecting the direction of Ampère force. Ask students to answer, the direction of the magnetic field and current. **Demonstration experiment** 2, explain while doing it, and give the experimental phenomenon. Ask students to record data on the black**board**. (The students do not know the meaning of the lines on the black**board**) **Lecture**: Through control variables method, the direction of the Ampère force is related to the direction of the current and the magnetic field. Ask students to come to the front to demonstrate with a model. Guide students to turn the model to be consistent, and find that the current and magnetic field have a specific relationship with the direction of Ampère force. **Lecture**: The left-hand rule.
		36:57-41:36	**Demonstration experiment** 3, introduce experimental equipment, give experimental phenomena, explain experimental principles, and guide students to answer. Apply the left-hand rule to explain the principle of a simple motor. Introduce the motor model and analyse it again.
		41:45-42:05	Summary: Ampère force magnitude, direction, left-hand rule
	Classroom management	0:00-0:04	**Class begins**
		2:10-2:25	**Board**: Ampère force
		2:53-3:14	**Introduction** of experimental equipment and conditions
		5:58-6:14	**Board**: magnitude, I∥magnetic field, F=0
		7:24-7:28	**Board**: I⊥magnetic field
		9:07-9:16	**Board**: magnetic field, I, L
		10:00-15:45	Introduce the experimental equipment and principle, and circuit **Assign** the experiment tasks of each group
		15:45-25:20	Oscar connected one group's circuit and guided them to complete the experiment
		27:35-28:19	**Board**: $F \propto L$, $F \propto I$, $F \propto IL$, F=kIL, F=BIL
		28:25-29:30	Introduce the experimental equipment
		33:32-34:05	Ask the student to go to the front and show the models
		36:40-36:50	**Board**: direction, left-hand rule
		36:57-37:19	Introduce the experimental equipment
		42:05-42:12	**Class is over**

Dimensions		Time	Comments
	Classroom discourse and interaction	7:52-9:00	I-R-F-Q-R-F-G-Q-R-Q-R
		10:25-12:27	I-R-E-Q(other)-R-F-Q-G-R-F-G-R-E(Perfect, sit down please)
		28:26-28:50	I-R-Q-R-E(Perfect, sit down please)
		37:46-39:10	A-I-R-Q-R-G-R-G-R-Q-R-Q-R-G-R

Table A4.0.9 F5

Dimensions		Time	Comments
Content knowledge	Scientific concept	11:00-11:06	Left-hand rule
		23:09-23:11	$I \perp B$, F=BIL
		27:58-28:05	$F = BIL \sin \theta$
	Scientific method	1:20-1:21	Experimental evaluation
Knowledge of student	Learning strategies		Make hypothesis based on questions, observe experiments, describe phenomena, and summarise conclusions. Apply and verify the conclusions. Deep learning.
	Misconceptions and prior knowledge	10:45-11:05	The student just read the text on the textbook without thinking.
Pedagogical knowledge	Instructional strategies	0:27-1:00	Review the definition of the Ampère force, introduce the direction and magnitude of Ampère force.
		1:10-11:52	Task: Explore the influence factors of the direction of Ampère force **Demonstration experiment** 1, introduce the experimental equipment, explain while doing it. Repeat twice Summarise the features of direction and ask students to answer it **Lecture**: left-hand rule, and apply the left-hand to determine the direction shown in the **Demonstration experiment**.
		11:53-22:29	**Exercise**: Apply the left-hand rule **Exercise**: Apply the left-hand rule to explain the interaction between two current-carrying wires. Ask students to analyse the interaction of currents in the same direction and practice the reverse current.
		22:30-30:18	Review the expression of magnetic induction strength, derive $I \perp B$, F=BIL, and give $I \parallel B$, F=0. Question: If it is neither parallel nor perpendicular? **Board**: the situation. **Lecture**: According to the board drawing, the first method is to project the length of the wire to the direction perpendicular to the magnetic field. Method two ask students to answer, get the vector decomposition of the magnetic field, follow the parallelogram rule. Get, F=BIL sinθ **Lecture**: Conditions: applicable to the uniform magnetic field, F is perpendicular to the plane formed by B and I, and B and I is not necessarily perpendicular with each other, so B does not necessarily penetrate vertically. **Exercise**: BI has an angle to determine the direction of Ampère force.

Dimensions		Time	Comments
		30:18-34:18	**Exercise**: determine the direction and magnitude of Ampère force.
		34:18-40:48	**Lecture**: Introduce the structure of magnetoelectric ammeter. **Lecture**: The characteristics of the magnetic field of the magnetoelectric ammeter: uniform radial distribution, the angle between the coil plane and the magnetic line of induction is 0 **Lecture**: Non-uniform magnetic **Lecture**: Introduce the principle of the magnetoelectric ammeter. **Lecture**: Advantages and disadvantages: the advantage of the magnetoelectric instrument is that it has high sensitivity and can measure feeble current; the disadvantage is that the wire of the coil is skinny and the allowable current is feeble.
		41:01-47:53	**Exercise**
		47:53-48:09	Summary: the magnitude of Ampère force and its calculation, the principle of Magnetoelectric Ammeter **Assign**ment
	Classroom management	0:20-0:26	**Class begins**
		1:01-1:10	**Board**: the direction of Ampère force
		1:44-8:50	Show Ampère Force Demonstrator **Board**: the direction of the current and magnetic field, the direction of Ampère force
		11:04-11:06	**Board**: left-hand rule
		17:37-20:30	Doing **Exercise**, Freddie walked around
		22:35-22:38	**Board**: the magnitude of Ampère force
		23:35-23:46	**Board**: I⊥B, F=BIL I∥B, F=0
		24:16-24:35	**Board**: Schematic diagram (the angle is 0°)
		26:40-27:39	**Board**: vector decomposition of magnetic induction intensity **Board**: $F = BIL\sin\theta$
		30:50-31:05	Doing **Exercise**, Freddie walked around
		34:20-35:34	**Board**: Magnetoelectric Ammeter Explain the structure
		36:18-37:48	**Board**: Uniform radial distribution **Board**: Schematic diagram
		38:05-38:10	**Board**: Non-uniform magnetic field **Board**: Schematic diagram

Dimensions		Time	Comments
		38:50-38:52	**Board**: the principle
		40:58-41:00	**Board**: Pros and cons
		41:20-43:24	Doing **Exercise**, Freddie walked around
		48:09-48:25	**Class is over**
	Classroom discourse and interaction	4:10-4:15	A-I-R-F(whole classroom interaction)
		9:11-11:05	A-I-R-F-Q-R-Q(other)-R-F-Q(other)-R-Q-R
		12:10-14:25	A-I-R-Q(whole)-F-Q-R-G-R-E-Q(whole)-G-R-Q(whole)-G-R
		15:40-17:04	A-I-R-G-R-Q-R-F
		25:55-26:30	A-I-S-Q-R-F
		29:10-29:23	I-R-F
		31:08-34:14	A-I-R-F-Q(whole)-F-Q(other)-R-Q-R-Q-R-Q(whole)-F-Q(other)-R-Q-R-G-R-G
		40:33-41:00	I-R-F
		43:24-47:53	A-I-R-Q1-S-R-F-Q2-R-Q-R-F-Q3-R-Q-R-G-F-Q4-G-R-Q-R-Q-R-F

Table A4.0.10 E1

Dimensions		Time	Comments
Content knowledge	Scientific concept	6:44-7:45	Electric field
		21:50-24:01	Electric field strength
		34:26-38:16	Superposition principle of the electric field
	Scientific method	9:30-11:00	Ideal model, the test charge
		21:30-21:40	The ratio definition method emphasizes that the electric field strength is not determined by the physics quantity in the formula, but is only defined by the ratio.
		36:05-36:27	Parallelogram rule, vector composition
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge	11:02-12:41	Prior knowledge: Coulomb's Law
Pedagogical knowledge	Instructional strategies	0:28-1:46	Review Coulomb's law, ask students to talk about it
		1:50-3:53	**Demonstration experiment**, use questions to trigger conjectures, why are the forces different Give learning tasks and ask students to read aloud
		3:53-6:44	**Lecture**: Task 1, how does the interaction between charges occur? In the history of science, Faraday proposed the concept of the electric field. Ask students to use the electric field to explain the interaction between charges The feature of the interaction between charges: there is no contact. Ask students to answer other non-contact forces. Summarize the key content of this lesson: the definition and nature of the electric field
		8:02-11:00	**Lecture**: The field source charge, ask students to name the probe charge and analyse the characteristics of the probe charge.
		11:02-24:01	**Lecture**: Task2, Explore the factors affecting the strength of the electric field: distance The most important content of this lesson: electric field strength **Example**: Calculate the Coulomb force, fill in the form, and find the relationship between force and field strength. Practice and discuss in groups. **Lecture**: Ask the students to say the result. Get E=F/q. Summary: Electric field strength, definition formula, E=F/q, applicable to all kinds of electric fields, vector, stipulation: The direction of the positive charge is the field strength direction

Dimensions		Time	Comments
		24:01-26:10	**Exercise**, to consolidate the knowledge learned. Ask students to answer it
		26:10-34:25	**Lecture**: Task 3, The determinants of electric field strength, explore the expression of the electric field strength of point charge. **Exercise**, ask students to write the results on the blackboard. Compare the two formulas and ask students to talk about it. **Exercise**, determine the direction of the field strength, ask students to post the direction on the blackboard Summary: The direction of the electric field strength of the point charge, the positive charge is radiant, and the negative charge penetrates the heart.
		34:25-37:03	**Lecture**: Task 4, Superposition principle of field strength **Exercise**: Ask a student to answer. Emphasize that the field strength has a direction
		37:04-41:10	**Exercise**: 1, Ask a student to answer it **Exercise**: 2, Ask the students to answer it
		41:10-42:01	Summary: Basic knowledge: electric field, objective existence, special substance. Electric field strength Basic method: the principle of electric field strength superposition, the parallelogram rule. Ratio definition method. Ideal model, test charge.
	Classroom management	0:00-0:07	**Class begins**
		0:10-0:27	**Board**: Electric field strength
		1:50-2:05	Introduce the experiment equipment
		6:44-7:45	**Board**: electric field 1generation: Special substances exist around the charge。 2 Basic properties: Has force effect on the charge placed in it
		13:45-18:14	**Exercise**: **Group discussion**, Ivy walk around
		21:50-24:01	**Board**: electric field strength, 1 Definition, E=F/q（all kind of electric field） 2 Unit: N/C 3 Vector, Rule: The direction of the force that experienced by the positive charge is the direction of the field strength
		26:55-27:30	**Board**: Point charge field strength **Exercise**: Ask students to do it on the blackboard,
		32:28-32:50	Ask students to mark the direction on the blackboard
		42:03-42:12	**Class is over**
	Classroom	0:47-1:28	I-R(volunteer)-G-R-E

Dimensions		Time	Comments
	discourse and interaction	2:14-2:32	A-I-R-Q-R-E(whole classroom interaction)
		2:50-3:25	A-I-R-Q-R-Q(whole classroom interaction)
		4:30-5:08	I-S-G-R-E(Perfect, sit down, please)
		5:25-6:40	I-R-Q-R-F/E-Q(other)-R-G-R-Q-R-FE-Q(whole)-R(whole)
		8:38-9:04	I-S-G-R-E(Perfect, sit down, please)
		9:47-10:30	I-R(whole)-Q-R(whole)-Q-R-F-Q(whole)-R
		11:02-12:41	I-S-R-EF-Q-R(whole)-Q-R(whole)-G-R(whole)-Q-R(whole)-Q-R(whole)-F
		18:33-20:30	A-I-R-F-Q-R-Q-R-Q-R-Q-R-F-R-FE-Q-R-E
		24:50-26:07	A-I-R-Q(other)-R-Q-R-Q(whole)-R-F
		28:00-28:17	A-I-R-E(whole classroom interaction)
		29:21-30:58	I-R-E-F-Q(other)-R-Q-R-F-Q(other)-R-F
		35:05-36:42	A-I-S-R-E-R-Q-R-Q-R-F-Q-R-F-Q-R-F-Q-R-Q-R-F-Q(whole)-R(whole)-F
		38:28-39:14	A-I-R(volunteer)-Q(whole)-R(whole)-Q-R-E-Q-R-Q-R-E
		40:50-41:10	A-I-R-F(whole classroom interaction)

Table A4.0.11 E2

Dimensions		Time	Comments
Content knowledge	Scientific concept	9:28-10:28	Electric field
		29:58-35:16	Electric field Strength
	Scientific method	7:45-7:48	Ideal model
		13:18-13:25	Experimental evaluation
		28:58-29:10	Ratio definition method
		38:48-41:01	vector composition
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge		Have learnt Coulomb's Law Mia asks students to preview, so the students should know what is said in the book about this lesson.
Pedagogical knowledge	Instructional strategies	0:09-1:58	**Introduction**: activity, shaking hands which have interaction, contact force, and introduce the non-contact force
		2:15-6:33	The history of science, action in a distance and field. (The video cannot be played, and Mia transferred the activity into the reading material on the textbook.) Question guide, characters, opinions
		6:33-10:28	**Lecture**: Field source charge, test charge (two small) **Demonstration experiment**, Introduce the experiment equipment and principles (In order to see the angle quantitatively, a protractor is added), explain while doing it. (Experimental operation specification: discharge after the experiment. However, it cannot be concluded that the electric field exists objectively.) The history of science: Faraday was also questioned and finally admitted The property of the electric field
		10:54-16:48	Question: the influencing factors of electric field strength **Group discussion** Ask a student to answer it. Mia summarised the factors that raised by students, distance and the charge. **Demonstration experiment**, explain while doing it.

Dimensions		Time	Comments
		16:48-35:16	Question: whether could we use the force to indicate the electric field strength or not? **Example**, guidance, ask students to do **Exercise** and complete the table。 Show the results. Mia concluded that the force could not be used as an indicator of the electric field strength. Question: then what quantity should we use? Ask students to observe the table and calculate the ratios. Show the results. Ask students to draw the graph, show the results Summary: the ratio could indicate the property of the electric field. Ask a student to write the definition formula, guide students to get the physics meaning of the definition formula Ask the students to mark the direction of the force and find that the direction of the positive and negative charges is different. **Lecture**: the direction of the force experienced by the positive charge at this point is the direction of the field strength **Exercise**: ask students to mark the direction of the field
		35:16-38:48	the electric field strength of point charge in vacuum **Example**, ask students to derive on the black**board** **Exercise**: activity, determine the direction.
		38:48-41:01	Superposition of electric field strength of point charge, follow vector composition. **Example**, Ask students to derive on the black**board**。
		41:01-41:30	Summary
	Classroom management	0:00-0:09	**Class begins**
		1:58-2:14	**Board**: Electric field strength
		7:54-8:20	Introduce the experiment equipment and principle
		9:28-10:06	**Board**: electric field, objective existence, a special substance
		10:28-10:53	**Board**: Has force effect on the charges placed in it
		11:02-11:19	**Assign** the discussion tasks
		18:28-19:24	**Assign Exercise**, and Mia walked around
		22:45-23:08	Students thinking and Mia walked around
		24:45-26:50	Students drawing and Mia walked around

Dimensions		Time	Comments
		29:13-29:40	**Board**: electric field strength
		37:47-37:57	**Board**: the electric field strength of point charge in a vacuum, $E=kQq/r^2$
		40:58-41:01	**Board**: the Superposition of electric field strength of point charge in vacuum
		41:30-41:38	**Class is over**
	Classroom discourse and interaction	0:40-1:55	A-I-R-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R(whole classroom interaction)
		3:34-6:07	[A-I-R-Q-R-Q-R(whole classroom interaction)]-Q-S-Q(other)-R-E-[Q-R-Q-R-L-Q-R-Q-L-Q-R-G-Q-R-Q-R-Q-R-(whole classroom interaction)]
		8:50-9:10	A-I-R-F-Q-R (whole classroom interaction)
		11:45-12:58	A-I-R-Q-R-Q-R-F-Q(other)-R-F-Q(other)-R-F-Q(other)-R-F
		14:07-14:35	A-I-R-F-Q-R-Q-R-Q-R-F (whole classroom interaction)
		15:36-15:54	A-I-R-Q-R-F (whole classroom interaction)
		17:30-18:28	A-I-R-Q-R-Q-R-G-Q-R (whole classroom interaction)
		20:05-20:18	I-R-E(whole classroom interaction)
		20:39-21:26	[I-R-Q-R-G-Q-(whole classroom interaction)]-Q-R-F
		24:13-24:35	A-I-G-R-F(whole classroom interaction)
		31:00-31:42	I-R-Q-R-F-Q-R(whole classroom interaction)

Table A4.0.12 E3

Dimensions		Time	Comments
Content knowledge	Scientific concept	7:35-7:44	Electric field
		20:10-23:40	Electric field strength
		27:05-28:48	Electric field line
		38:24-38:36	Uniform electric field
	Scientific method	21:05-21:18	Ratio definition method
		37:10-37:14	Parallelogram rule
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge		Students had previewed, so the students should know the knowledge.
Pedagogical knowledge	Instructional strategies	0:10-3:54	**Introduction**: Contact force and Non-contact force, review the Coulomb force from the previous lesson **Demonstration experiment** 1, the Coulomb force is non-contact force。
		3:54-7:44	The history of science, Faraday, introduce electric field. Apply electric field to explain the Coulomb force Summary: the electric field is a special substance that exists objectively, Has force effect on the charges placed in it。
		7:44-9:40	Question: How to check the existence of the electric field? **Lecture**: In the electric field, the charges would experience a force. Introduce the test charge and field source charge
		9:40-23:40	**Lecture**: Review the **Demonstration experiment** done in the previous lesson. The force is related to the distance and the electric field strength should be different in each area. Question: the electric field strength of the point charge **Example**, according to Coulomb's Law, calculate the force experienced by each charge. Ask students to do the **Exercise**, and Emily walked around。 Ask a student to answer it, summarize the law, electric field strength $E=F/q$。 **Lecture**: Ratio definition method, its physics meaning, unit, vector and the rule of direction

Dimensions		Time	Comments
		23:40-27:05	**Lecture**: Based on Coulomb's Law, derive the electric field strength of point charge and get the determination formula of electric field strength **Classroom discussion**: the direction of point charge electric field strength
		27:05-28:48	**Lecture**: electric field line, Features: artificial imaginary, do not intersect and do not close, the density could represent strength. It will be introduced in detail in the next class.
		28:48-33:39	**Exercise**: 1, Ask a student to answer it
		33:39-38:14	**Exercise**: 2, Guide the students to answer it, give the superposition principle of field strength which follows the parallelogram rule。
		38:14-39:14	**Lecture**: different electric field distributions, uniform electric field, point charge
		39:14-39:53	Application of electric field strength, generator of negative oxygen ion
		39:53-41:20	Ask students to summarize under Emily's guidance
		41:20-41:35	**Assignment**
	Classroom management	0:00-0:10	**Class begins**
		1:53-2:30	Introduce the experiment equipment, and ask students to assist
		4:41-4:49	**Board**: electric field
		7:28-7:46	**Board**: the electric field is a special substance that exists objectively. Property: Has force effect on the charges placed in it
		9:06-9:30	**Board**: test charge, field source charge
		13:48-16:07	**Assign** calculation tasks for each group, **Assign** the discussion tasks, Emily walk around
		19:18-19:46	**Board**: Electric field strength, E=F/q
		21:23-23:11	**Board**: Ratio definition method, Unit N/C, vector: the direction of the force experienced by the positive charge
		24:44-24:56	**Board**: point charge, $E=kQq/r^2$
		35:50-36:09	**Board**: Superposition of field strength
		41:18-41:22	**Board**: the distribution of electric field
		41:50-41:57	**Class is over**
	Classroom discourse and interaction	2:08-3:35	A-I-R-Q-R-Q-R-Q-R-A-Q-R-A-Q-R-Q-R-E(whole classroom interaction)
		10:00-10:45	I-S-Q-R-Q-R-Q-R-Q-R(whole classroom interaction)
		12:04-12:13	I-S-Q-R-Q-R-Q-R-Q-R (whole classroom interaction)
		16:13-17:47	A-I-R-E-Q(other)-R-E-Q(other)-R

Dimensions		Time	Comments
		23:45-24:54	I-S-G-R-F (whole classroom interaction)
		26:17-26:50	I-S-G-R-Q-OR (whole classroom interaction)
		29:55-33:39	A-I-R-F-Q(other)-R-Q-OR-Q(other)-R-Q-OR-Q-OR-Q-OR-Q-OR-Q(other)-OR
		34:28-35:45	A-I-R-Q-OR-F-Q-OR-Q-OR(whole classroom interaction)
		40:03-41:20	I-S-R-Q-G-R-F

Table A4.0.13 E4

Dimensions		Time	Comments
Content knowledge	Scientific concept	8:14-9:23	Electric field
		23:26-31:00	Electric field strength
	Scientific method	26:30-26:32	Ratio definition method
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge	1:58-2:34	Coulomb's Law
Pedagogical knowledge	Instructional strategies	0:07-8:14	**Demonstration experiment**, Ionizing ball, the bulb will light up close to the ionization ball. Introduce the electric field. **Review** the Coulomb's Law, the interaction between the charges does not require contact Non-contact force, does its interaction need a medium? The history of physics, action in a distance, Faraday, **Assign** reading task. Ask a student to read the text.
		8:14-9:23	**Lecture**: the definition and basic property of the electric field
		9:23-31:00	**Lecture**: Review the **Demonstration experiment** of Coulomb force, schematic diagram, electric field has strength. **Question:** How to indicate the strength of the electric field? Introduce field source charge and test charge, guide to summary the properties of the test charge **Demonstration experiment**, flash, ask students to talk about the result Ask students to complete the table. **Lecture**: electric field strength, definition, physics meaning, unit, vector
		31:00-33:32	**Exercise:** 1, ask a student to read the question and answer it.
		33:32-38:18	**Exercise:** 2, derive the formula of point charge field strength under Ella's guidance
		39:27-41:28	**Lecture**: If there are multiple field source charges in space, what would the electric field strength be? Superposition principle of field strength. **Assign**ment: Principle of field strength superposition
	Classroom management	0:00-0:07	**Class begins**
		1:28-1:38	**Board**: electric field strength

Dimensions		Time	Comments
		3:30-5:02	**Assign** reading tasks, and Ella walked around
		8:14-9:23	**Board**: Electric field is an objective substance Basic property: Has force effect on the charges placed in it
		16:15-18:02	**Assign Exercise**: Complete the table, Lin walked around
		19:56-21:43	**Exercise**: Complete the table, Lin walked around
		23:10-23:14	What the teacher emphasizes is the main point!
		23:26-23:56	**Board**: Electric field strength
		26:00-29:07	**Board**: E=F/q, Ratio definition method, all kinds of the electric field Physics meaning Unit N/C=V/m Vector, the direction of the force experienced by the positive charge
		34:30-34:32	Ask students to calculate **Board**: Point charge field strength, derive
		38:37-39:18	Ask students to complete their documents, and Ella walked around
		41:55-42:05	**Class is over**
	Classroom discourse and interaction	0:14-1:28	A-I-R-Q-R-Q-R-Q-R-Q-R-L-Q-R-E (whole classroom interaction)
		1:58-2:34	I-R-G-R-E
		2:42-2:45	I-R-F (whole classroom interaction)
		5:02-6:09	A-I-R-E-Q-R-Q-R-Q-R-Q-R
		6:24-8:14	I-R-Q-R-G-R-Q-R-E-[Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-E](whole classroom interaction)
		8:20-8:28	I-R-E
		9:15-9:30	I-R-E
		9:55-11:40	A-I-R-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R (whole classroom interaction)
		12:33-13:58	I-R-Q-R-Q-R-Q-G-R-E-F
		15:06-15:50	A-I-R-Q-R-L-Q-R-E
		18:02-20:00	A-I-R-Q-R-Q-R-Q-R-E-[Q-R-L-Q-R-Q-R-Q-R-Q-R-Q-R-G-R(whole classroom interaction)]
		21:44-23:15	A-I-R-F-Q-R-F-[Q-R-E-Q-R-Q-R(whole classroom interaction)]
		23:56-26:00	I-R-F-Q-R-Q-R-Q-R-Q-R-Q-R-Q(other)-R-Q-R-Q-R-Q-R-Q(other)-R
		26:12-26:26	I-R-Q-R-Q-R-Q-R-E
		27:10-27:20	I-R-E

Dimensions		Time	Comments
		28:45-29:07	I-R-F (Ella chose the one who cut into Ella's speech and gave a wrong answer)
		29:24-33:27	[I-R-Q-R-Q-OR-Q-OR-Q-OR-Q-OR-E-Q-R-G-R-L-Q-R-Q-R(whole classroom interaction)]-Q-R-Q-R-Q-R-G-R(whole)-E-Q(other)-R-Q-R-Q-R-Q-R-E-I(S)-R(T)-E(this is a good question)
		34:05-34:32	A-I-G-R-Q-R-Q-R (whole classroom interaction)
		35:06-38:05	A-I-R-E-R-F-E-[Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-R-G-R-Q-OR-E(whole classroom interaction)]
		39:48-41:28	A-I-R-Q-R-F (whole classroom interaction)

Table A4.0.14 E5

Dimensions		Time	Comments
Content knowledge	Scientific concept	5:01-9:02	Electric field
		16:05-23:24	Electric field strength
		28:30-39:11	Superposition principle of the electric field
	Scientific method	2:10-2:18	Use concrete things to describe abstract things
		28:59-29:03	Parallelogram rule
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge		Prior knowledge: Coulomb's Law, ratio definition method, parallelogram rule
Pedagogical knowledge	Instructional strategies	0:09-2:18	**Introduction**: describe spring, use concrete things to describe abstract things.
		2:30-9:18	Review the **Demonstration experiment** of Coulomb's Law in the previous lesson, schematic diagram. Faraday put forward the concept of field. An animation showed the interaction between charges. **Lecture**: The definition and properties of the electric field. Analogy, to the description of wind
		9:18-16:13	**Lecture**: Observe the schematic diagram of the **Demonstration experiment**, and get different deflection angles at different distances. Question: Can the force be used to indicate the strength of the field? **Group discussion**, ask students to talk about the results of the discussion and get the definition of electric field strength.
		16:13-23:24	**Example**, analyse and derive the determinant formula of point charge electric field strength. Compare and analyse the two formulas. **Lecture**: Electric field strength, Unit, Vector, Direction
		23:24-24:03	**Exercise**: 1, Ask the students to answer together, without explaining

Dimensions		Time	Comments
		24:03-39:11	**Exercise** 2: Ask a student to answer it, and change the conditions of the question, guide students to answer it, and elicit the superposition of field strength, then, get the principle of field strength superposition-parallelogram rule. Summarize the superposition law of point charge field strengths in a different area, on the vertical line, decrease on both sides; on the connection line, decrease first and then increase; symmetrical point, equal in magnitude and reverse in direction. **Group discussion**, the superposition law of field strength of two dissimilar point charge, ask students to explain on the black**board**
		39:11-39:50	**Exercise**: 3, ask students to answer it
		39:50-40:48	Summary: Knowledge, electric field, electric field strength, Superposition of field strength Method, Ratio definition method, use concrete things to describe abstract things **Assign**ment Call back to the description of spring
	Classroom management	0:00-0:09	**Class begins**
		2:18-2:30	**Board**: Electric field strength
		5:01-5:07	**Board**: Electric field
		6:45-6:53	**Board**: Electric field is an objective substance
		8:10-8:15	**Board**: Materiality
		12:49-14:08	**Assign** the discussion tasks, and Daisy walked around
		14:56-16:13	**Board**: Electric field strength, E=F/q
		17:32-17:43	**Board**: $E=kQq/r^2$
		21:01-22:45	**Board**: Unit N/C, vector, the direction of the force experienced by the positive charge
		28:01-28:30	**Board**: Superposition principle of field strength
		29:01-34:10	**Board**: Parallelogram rule **Board**: on the vertical line, decrease on both sides; on the connection line, decrease at first and then increase; symmetrical point, equal in magnitude and reverse in direction.
		34:20-36:07	**Assign** the discussion tasks, and Daisy walked around
		38:40-39:11	**Board**: Increase at first and then decrease; decrease at first and then increase; equal in magnitude and reverse in direction.
		40:48-40:55	**Class is over**
	Classroom	0:13-1:35	I-R-Q(other)-R-Q(other)-R-Q(other)-R-Q(other)-R

Dimensions		Time	Comments
	discourse and interaction	2:53-3:45	A-I-S-G-R-G-Q-R-E (whole classroom interaction)
		4:55-4:59	A-I-R-F (whole classroom interaction)
		5:13-5:35	I-R(whole)-Q-S-R-Q-R-Q(other)-R-Q(other)-R-F
		7:15-8:10	I-S-G-R-F-Q-R(whole)-F
		9:20-12:49	A-I-R-Q-R-OR-Q-R-L-Q-R-E-L-Q-R-F-L-Q-R-L-Q-R-Q-R-F (whole classroom interaction)
		14:10-16:12	A-I-S-R-F-Q-R-F-Q(other)-R-Q-R(whole)-F-Q(other)-R-E
		16:56-17:32	A-I-OR-L-Q-OR-F (whole classroom interaction)
		18:15-20:49	I-R-E-Q-R-Q-R-Q-G-R-F-Q-R-Q-R-Q-R-F (whole classroom interaction)
		21:34-21:56	I-R-Q-OR-F (whole classroom interaction)
		23:34-24:03	A-I-S-R-F (whole classroom interaction)
		24:40-28:00	A-I-S-R-E-Q-R-E-[Q-R-Q-R-Q-R-Q-R-G-Q-R-F (whole classroom interaction)]
		28:46-29:03	A-I-R-Q-R-F (whole classroom interaction)
		29:40-29:58	I-S-F (whole classroom interaction)
		30:35-31:27	I-R-F-Q-R-F-Q-R-F (whole classroom interaction)
		33:05-33:30	I-R-Q-R-Q-R-F (whole classroom interaction)
		36:07-38:40	A-I-R-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R-F
		39:40-39:50	A-I-R-F (whole classroom interaction)

Table A4.0.15 E6

Dimensions		Time	Comments
Content knowledge	Scientific concept	2:49-8:50	Electric field
		20:15-24:54	Electric field strength
		33:34-38:34	Superposition principle of the electric field
	Scientific method	21:21-22:30	Ratio definition method
		36:00-36:22	Parallelogram rule
		38:34-39:14	Infinitesimal method
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge		Prior knowledge: Coulomb's Law, ratio definition method, parallelogram rule
Pedagogical knowledge	Instructional strategies	0:00-2:49	**Introduction**: activity, shaking hands, contact force. Review the **Demonstration experiment** of Coulomb's Law, non-contact force. The debate in the history of science, then introduce the concept of the electric field
		2:49-9:19	**Lecture**: The definition of the electric field. Briefly introduce Maxwell's development of electromagnetic theory, which serves as an anchor to pave the way for subsequent learning. Apply electric field to explain the generation of Coulomb force. **Group discussion**, Ask the student to answer it. Introduce test charge and field source charge, and the characteristics of the test charge.
		9:19-27:24	Observe the results of the **Demonstration experiment**, and conclude that the electric field has strength. **Demonstration experiment**, explain while doing it. Explore: how to express electric field strength? Ask students to fill out the form. Ask a student to answer it under Hannah's guidance. Get E=F/q. Definition, unit and vector of electric field strength. (Mathematically derived that electric field strength is a vector, force is a vector and charge is a scalar) Classroom activity, demonstrate the direction of electric field strength.
		27:24-32:06	The expression of the electric field strength of the point charge is derived, ask students to do the **Exercise**.
		32:06-33:34	Ask a student to write the derive process on the black**board**, and Hannah explains.

Dimensions		Time	Comments
		33:34-38:34	Props demonstration, and ask students to answer the direction of electric field strength. Introduce the superposition of electric field strength, ask students to do the calculation **Exercise** under Hannah's guidance. Hannah explained and got the superposition principle of field strength which follow the parallelogram rule.
		38:34-39:48	**Assign**ment, calculate the field strength of the spherical field source charge. Hannah reminded: the infinitesimal idea and the principle of field strength superposition could be used to derive the field strength of the spherical field source charge. The result is the same as the field strength of a point charge placed in the middle of the sphere.
		39:48-41:20	Summary: Electric field, Electric field strength, Superposition of field strength
	Classroom management	2:54-3:45	**Board**: Electric field is the special substance that exists around the charge
		5:16-6:04	**Assign** the discussion tasks, and Hannah walked around
		8:50-9:02	**Board**: Property, Has force effect on the charges placed in it
		11:00-12:00	**Demonstration experiment**
		13:30-16:45	**Assign Exercise** tasks, and Hannah walked around
		20:15-24:49	**Board**: Electric field strength, E=F/q, ratio definition method, unit N/C, vector, direction: the same with the direction of the force experienced by the positive charge and opposite to the direction of the force experienced by the negative charge
		25:15-27:17	Ask students to cooperate with class activity and show the direction of the electric field
		27:24-27:53	**Board**: the electric field strength of point charge
		28:15-29:17	**Assign Exercise** tasks, and Hannah walked around
		29:30-30:00	Ask students to write the derive process on the blackboard
		32:32-36:47	**Board**: superposition of electric field strength **Assign Exercise** task, and Hannah walked around
	Classroom discourse and interaction	6:04-7:14	A-I-S-R-F-Q-R-Q-R-E
		9:19-10:43	I-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-F (whole classroom interaction)
		16:50-19:25	A-I-R-Q-R-Q-R-F-Q-RO-Q-R-Q-R-Q-R-E-G-R-F-Q-R-Q-R-E
		30:40-31:58	A-I-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-G-OR-Q-OR-Q-OR-F (whole classroom interaction)
		32:12-33:35	A-I-OR-Q-OR-Q-OR-Q-OR-G-Q-OR-Q-OR-Q-OR-F (whole classroom interaction)
		36:00-36:22	A-I-R-F-Q-R (whole classroom interaction)

Dimensions		Time	Comments
		37:20-38:30	A-I-RO-Q-RO-Q-RO-Q-G-RO-Q-RO-F (whole classroom interaction)
		39:52-40:45	I-R-Q-R-Q-OR-Q-OR-Q-OR-Q-RO (whole classroom interaction)

Table A4.0.16 E7

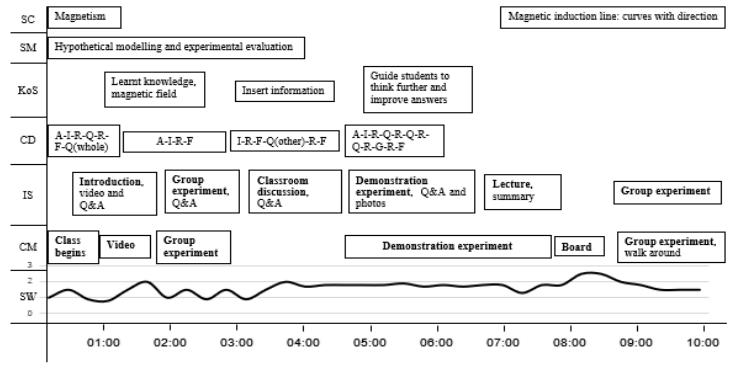
Dimensions		Time	Comments
Content knowledge	Scientific concept	2:00-13:16	Electric field
		24:56-36:00	Electric field strength
	Scientific method	19:37-19:40	Control variable method
		27:14-27:17	Ratio definition method
Knowledge of student	Learning strategies		Make a hypothesis based on the problem, summarize the law, apply and check whether the law is consistent. Deep learning
	Misconceptions and prior knowledge		Prior knowledge: Coulomb's Law, ratio definition method, parallelogram rule
Pedagogical knowledge	Instructional strategies	0:11-1:29	**Introduction**: clap hands, contact force **Demonstration experiment** (Electrified ball and foil ball), non-contact force How to achieve interaction without contact?
		2:00-13:16	Review the non-contact force, magnetic field, and gravitational field that students had learned. Introduce the interaction between the charges is realized through the electric field. The history of physics of the field, **Assign** the task of searching for information. Ask students to read aloud the materials found, Luna summarized. **Lecture**: How to explore the existence of the electric field? Looking back at the lower-secondary school, the method that proves the existence of a magnetic field is to analogy to the magnetic field. Guide students to use the properties of the electric field, has a force effect on the charges placed in it, to verify the existence of the electric field. **Lecture**: introduce the test charge and field source charge, and the characteristics of the test charge.

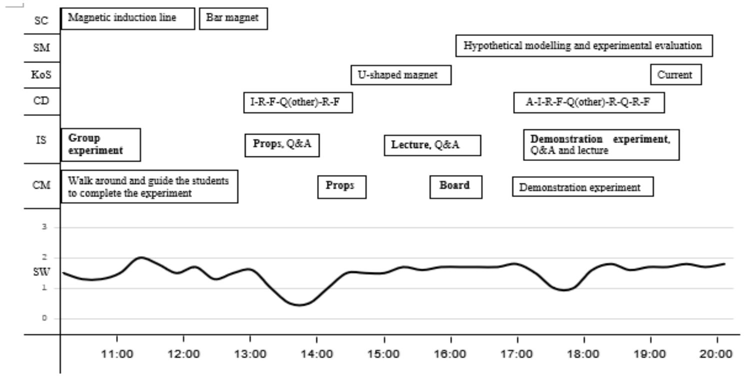
Dimensions		Time	Comments
		13:16-28:50	**Demonstration experiment**, it is found that the deflection angle is related to the distance, and the electric field has strength. **Exercise**: ask students to fill out the form, show the scores of each group, and praise the full score groups. The submission result of one of the full score groups is displayed without explanation. Guide to observe the laws presented in the table, **Group discussion**. Ask a student to answer it, get E=E/q. Ask students to talk about the unit and physics meaning of electric field strength. **Demonstration experiment**, to explore the direction of electric field strength. Observe the direction of force at different positions. **Lecture**: the direction of the force experienced by the positive charge is the electric field strength direction at the point
		28:50-32:20	Classroom activity, demonstrate the field strength direction. Summary: the magnitude and direction of field strength.
		32:20-36:00	Question: It is irrelated with test charge. What determines the field strength? Analogy, the fluorescent lamp as the field source charge, eyes like test charge, the field strength is determined by field source charge. Ask students to derive the formula of point charge field strength under Luna's guidance, and Luna explained it.
		37:13-39:18	Class activity, demonstrate the field strength direction of different field source charges and consolidate the concept that the field source charge determines the field strength.
		39:18-40:38	Summary: The nature of the electric field, the definition of electric field strength, the determinant formula of point charge electric field strength. Insert the anchor point, the nature of the electric field **Assign**ment: preview electric field line
	Classroom management	0:00-0:11	**Class begins**
		0:50-1:10	Introduce the experiment equipment
		1:31-2:00	**Board**: Electric field strength
		4:08-6:36	**Assign** data search task (with Pad), Luna walked around
		10:10-10:40	**Board**: Has force effect on the charges placed in it
		13:16-13:36	**Demonstration experiment**
		14:13-18:14	**Assign Exercise** (with Pad), Luna walked around

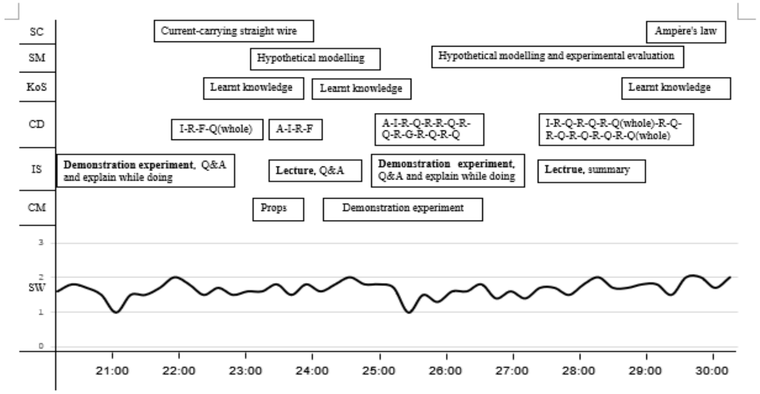
Dimensions		Time	Comments
		19:48-21:59	**Assign** the discussion tasks, Luna walked around
		25:21-27:16	Let the students write down the definition and unit of electric field strength **Board**: Electric field strength, E=F/q, unit N/C, ratio definition method
		27:40-28:00	**Demonstration experiment**
		28:23-28:43	**Board**: The direction of the force experienced by the positive charge is the direction of the electric field strength at the point.
		28:54-31:35	Classroom activity, show the direction of field strength
		33:49-35:09	**Board**: **Example**, ask students to derive on the blackboard, Luna walked around
		36:00-36:22	**Board**: Decisive formula of point charge electric field strength, E=kQq/r2
		40:38-41:37	**Assign**ment: Preview and then let students read the textbook.
		41:37-41:49	**Class is over**
	Classroom discourse and interaction	2:08-3:20	I-S-OR-Q-OR-E-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-Q-OR-E-L-Q-RO (whole classroom interaction)
		6:40-8:10	A-I-RO (whole)-Q-R-E-Q(other)-R-E
		9:03 -10:10	I-R-E-G-Q-R-Q-R-Q-R-Q-R-Q-R-Q-R-F (whole classroom interaction)
		11:10-13:15	I-[R-Q-R (whole classroom interaction)]-Q-R-Q-S-Q-R-F-[Q-R-Q-OR-Q-OR-Q-OR-Q-OR (whole classroom interaction)]
		13:30-14:05	A-I-R(whole)-Q-R-Q-R-Q-R-E
		19:20-19:48	A-I-R-F-Q-OR (whole classroom interaction)
		21:08-24:34	A-I-R-Q-R-E-Q(other)-R-Q-R-Q-R-Q-R-E-G-Q-S-G-R(whole)-Q(other)-S-R-Q-R-E-Q-OR(whole)
		25:35-25:49	A-I-R-E
		26:02-27:13	I-R(whole)-Q-R-Q-OR-Q-G-R-E
		27:27-27:40	I-R-F (whole classroom interaction)
		27:59-28:23	A-I-R-Q-R-Q-R-F (whole classroom interaction)
		31:00-31:15	A-I-R-Q-RO (whole classroom interaction)
		33:12-33:49	I-R-Q-RO-Q-RO-Q-RO-Q-RO(whole classroom interaction)
		35:14-36:00	A-I-R-Q-RO-Q-R-Q-R-Q-OR-Q-R-F (whole classroom interaction)
		38:42-39:18	A-I-G-R-Q-R-E-Q-R (whole classroom interaction)

Appendix 5: Discourse structure

Table 1 M1 Discourse structure







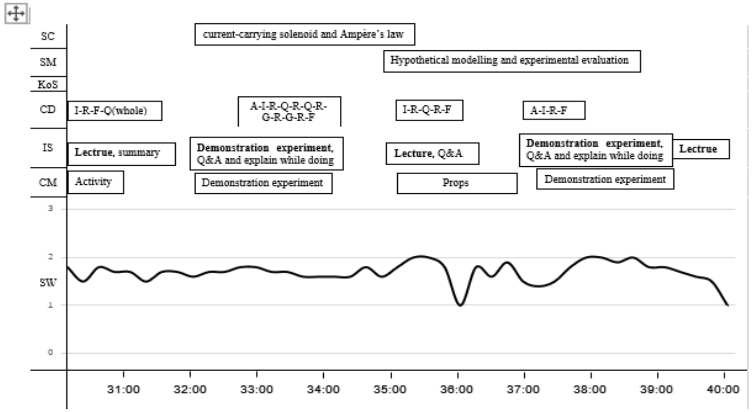


Table 2 M2 Discourse structure

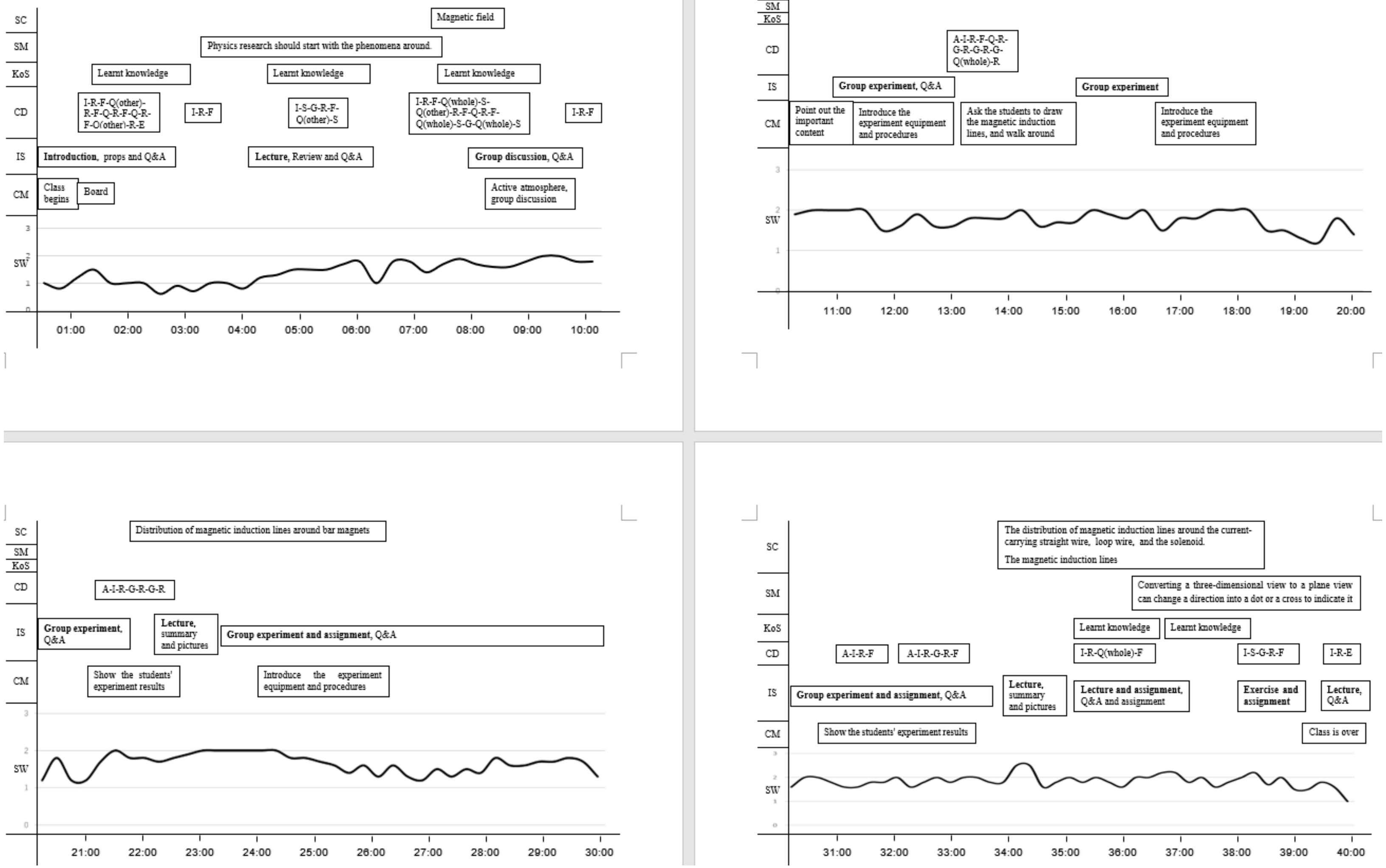


Table 3 M3 Discourse structure

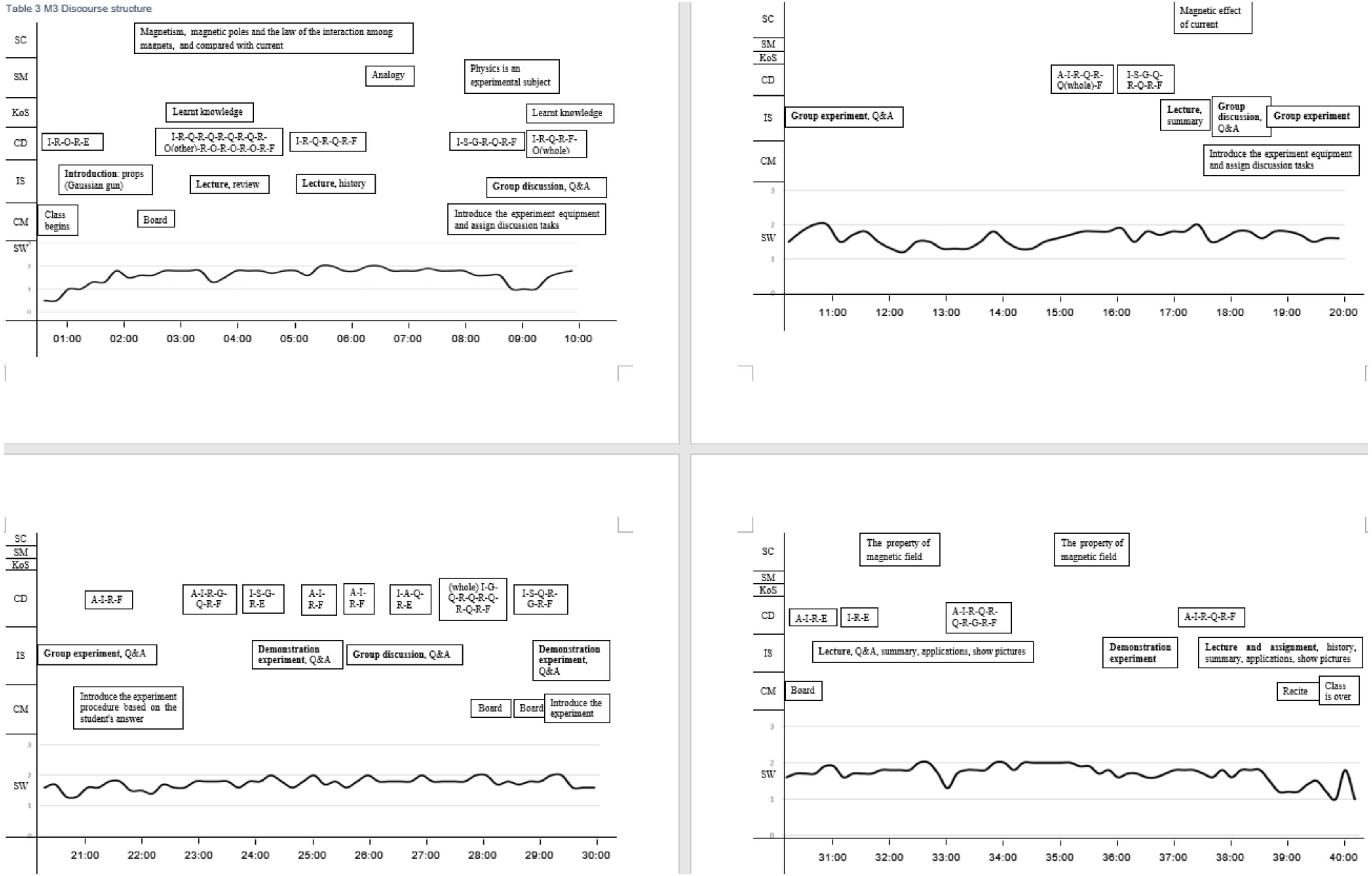


Table 4 M4 Discourse structure

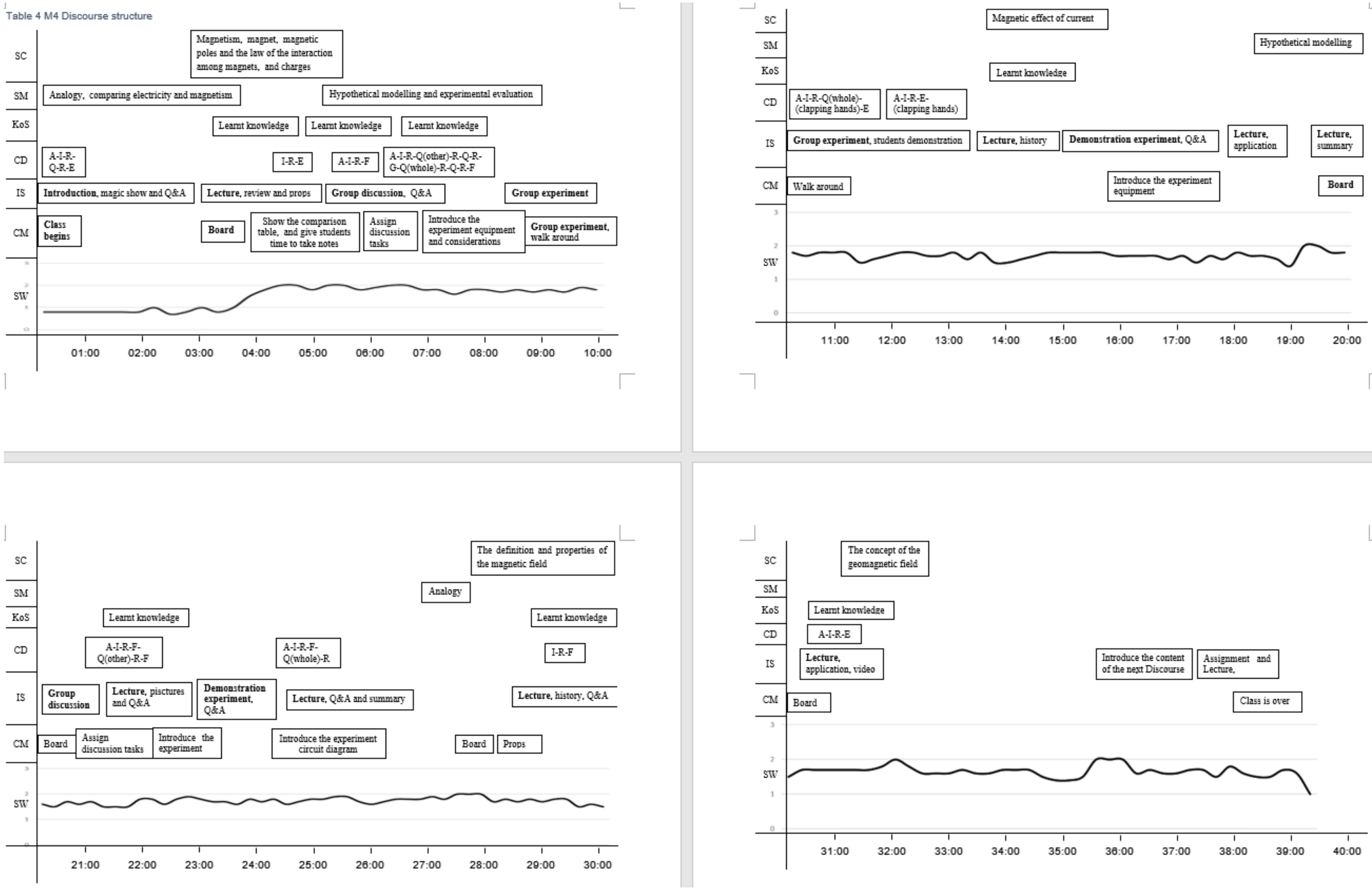


Table 5 M5 Discourse structure

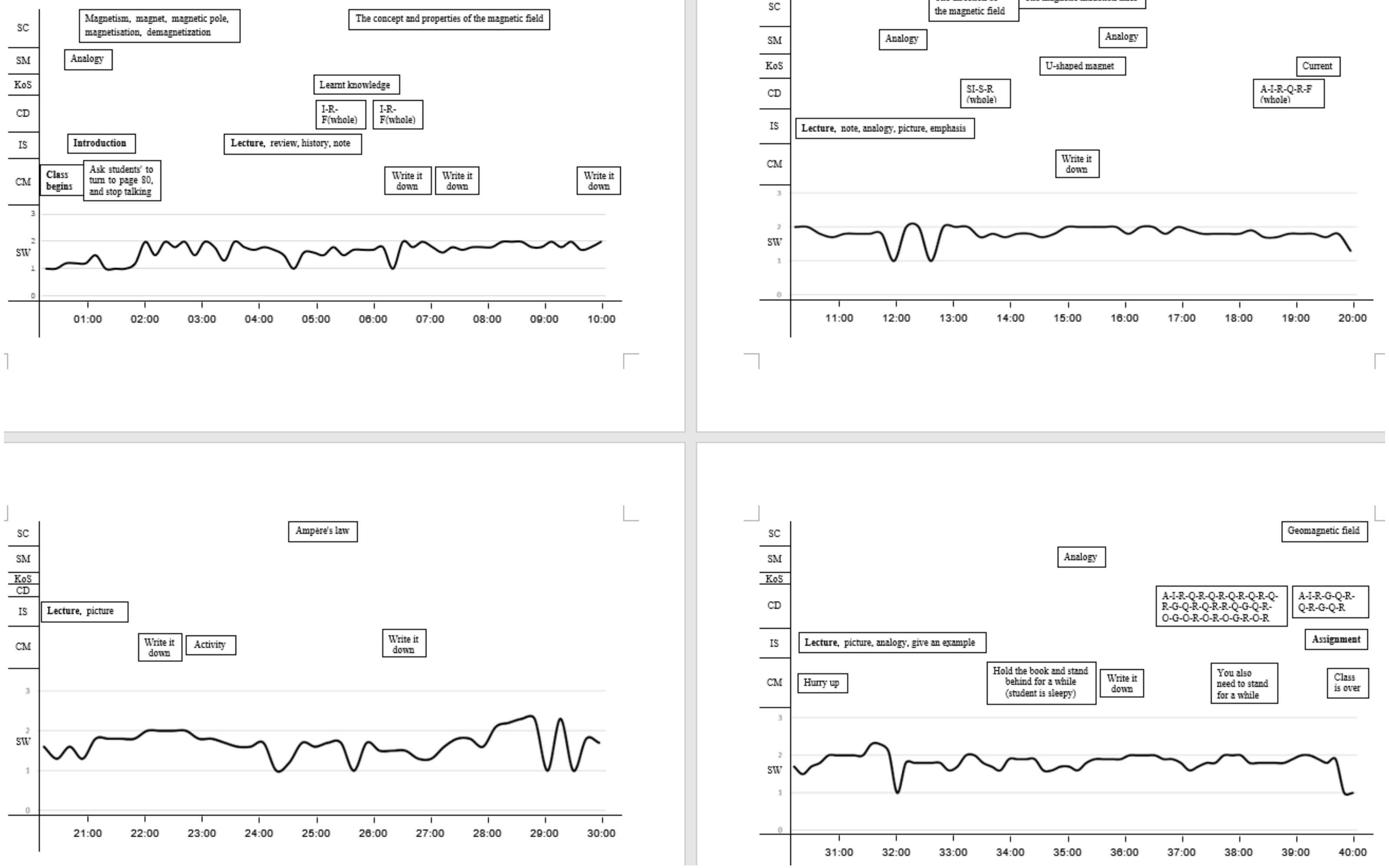
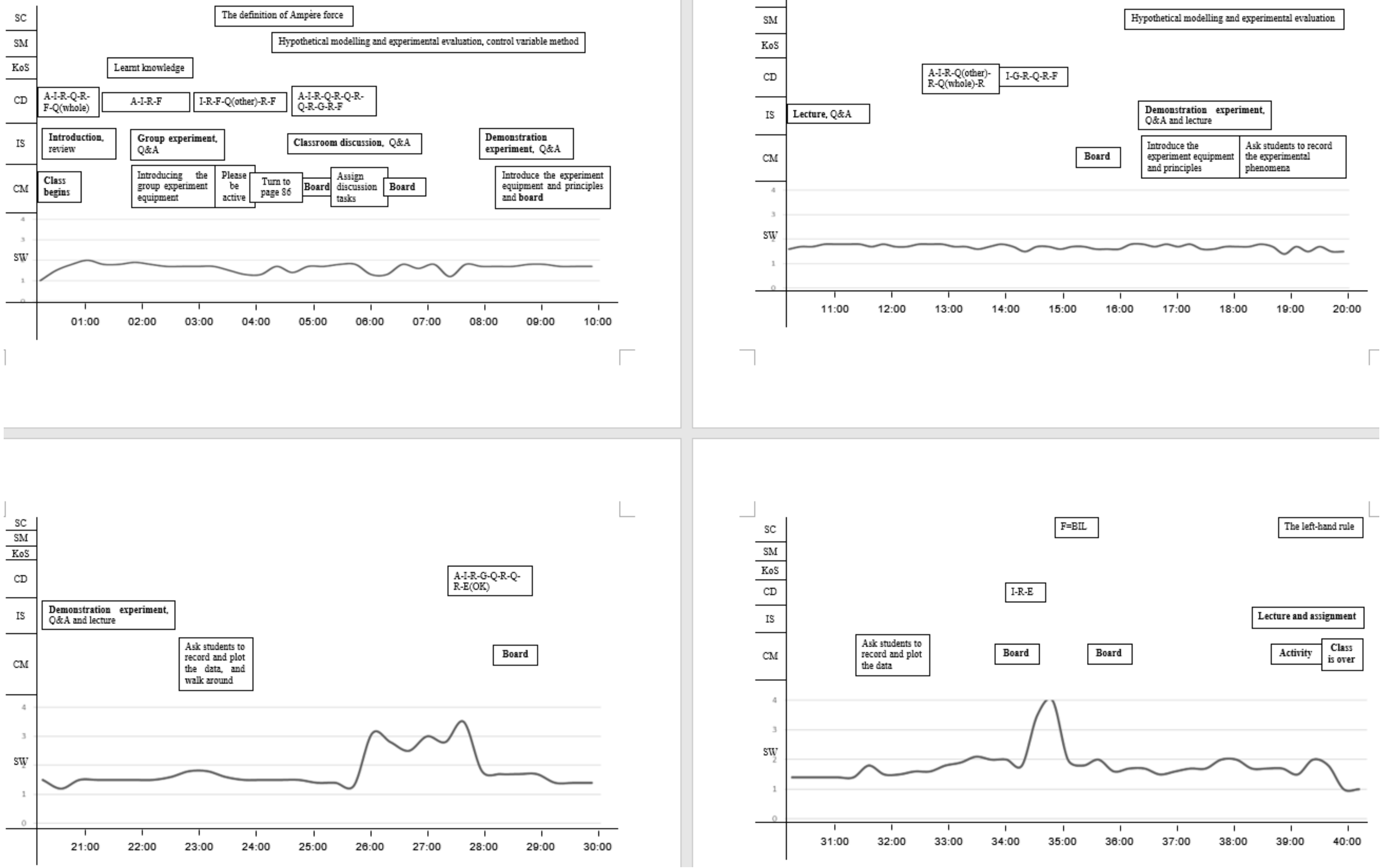


Table 6 F1 Discourse structure



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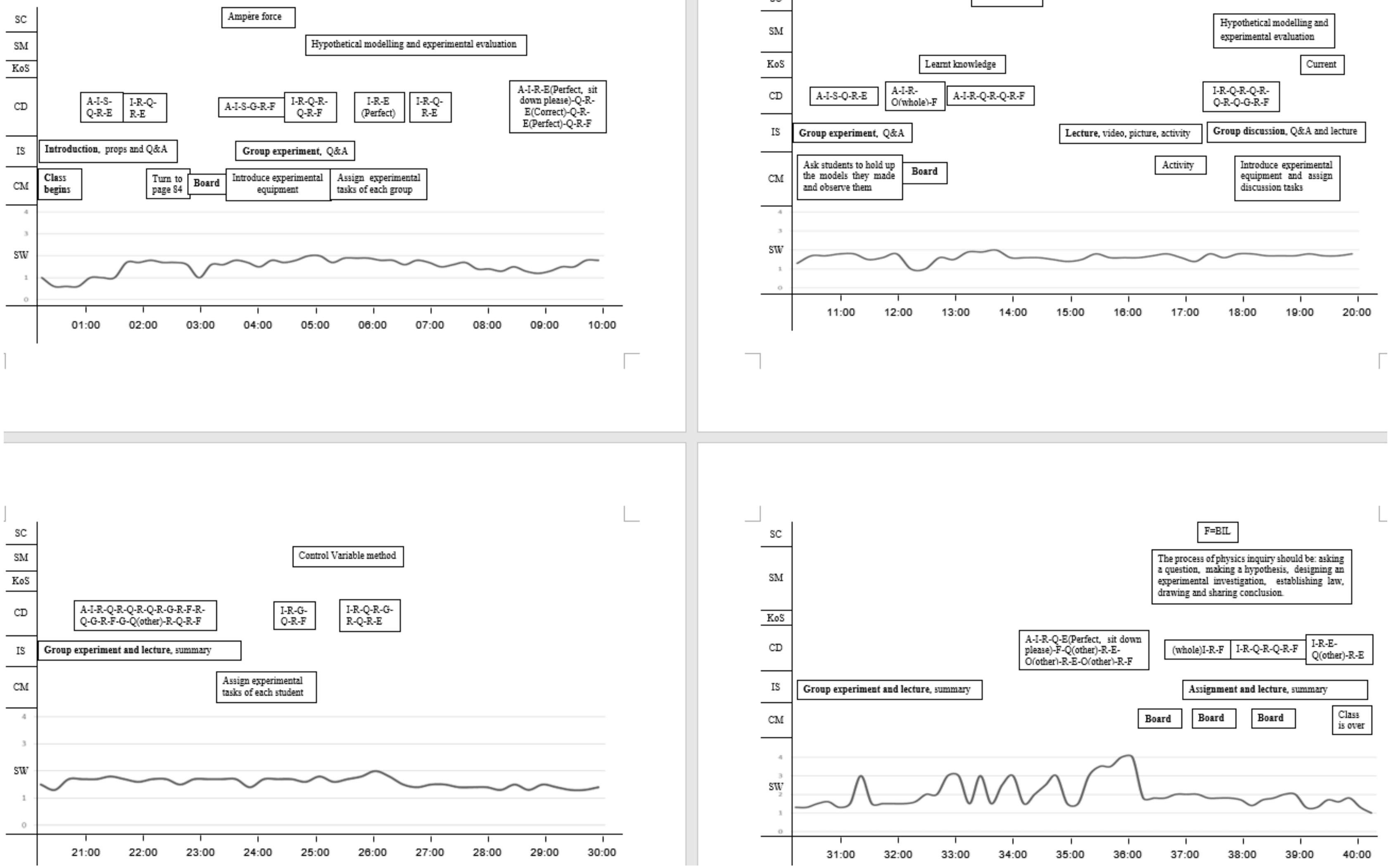

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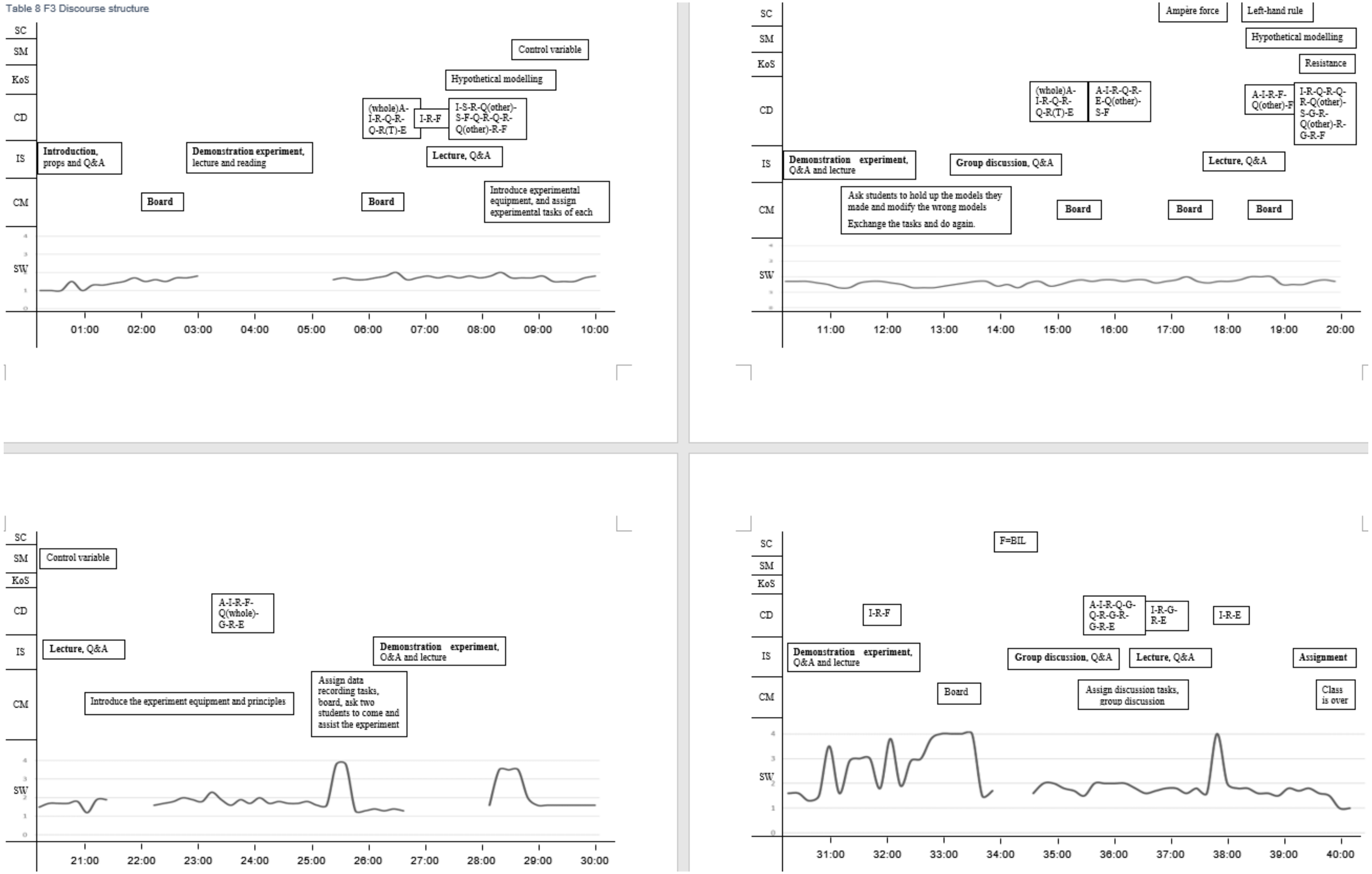
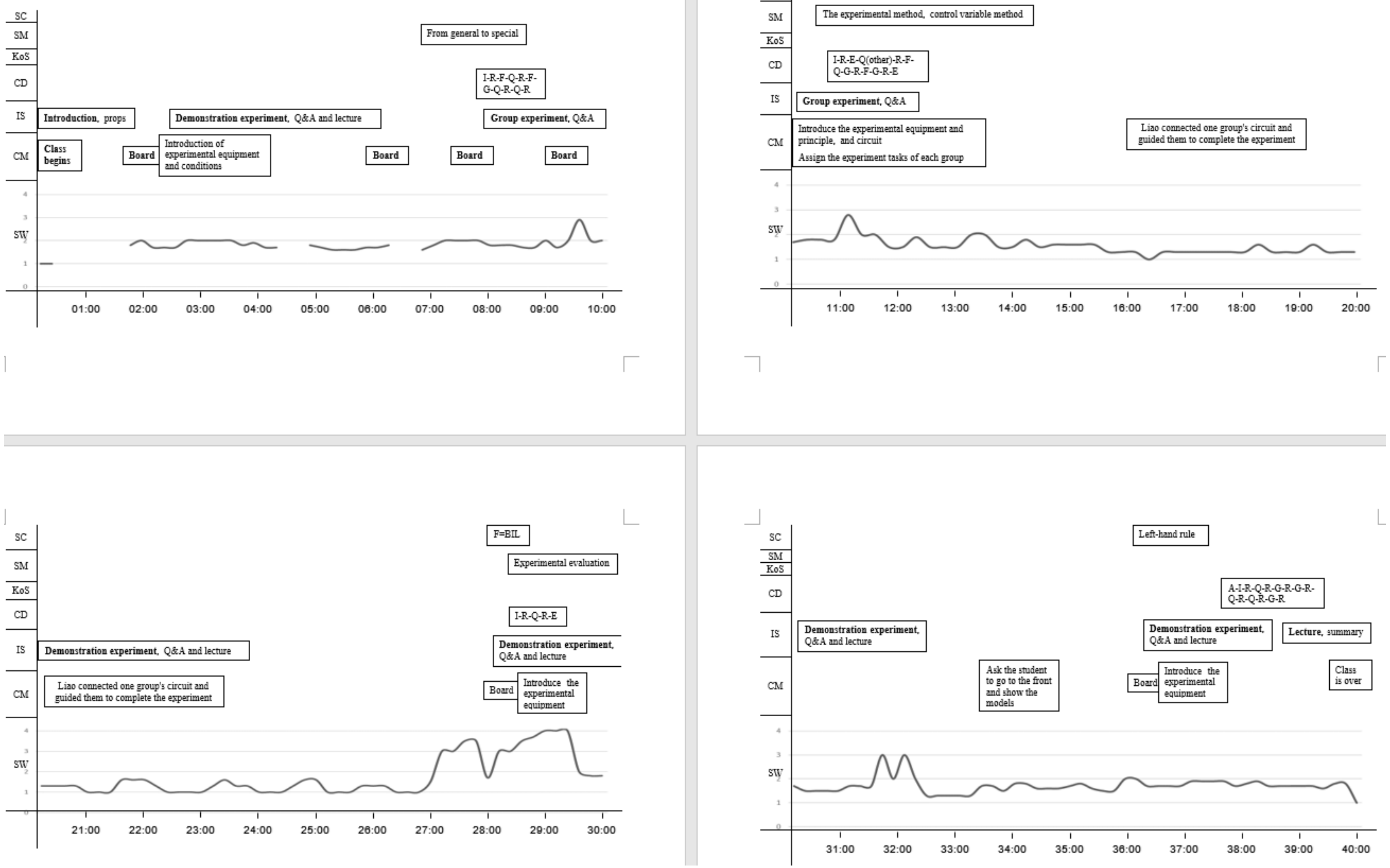


Table 9 F4 Discourse structure



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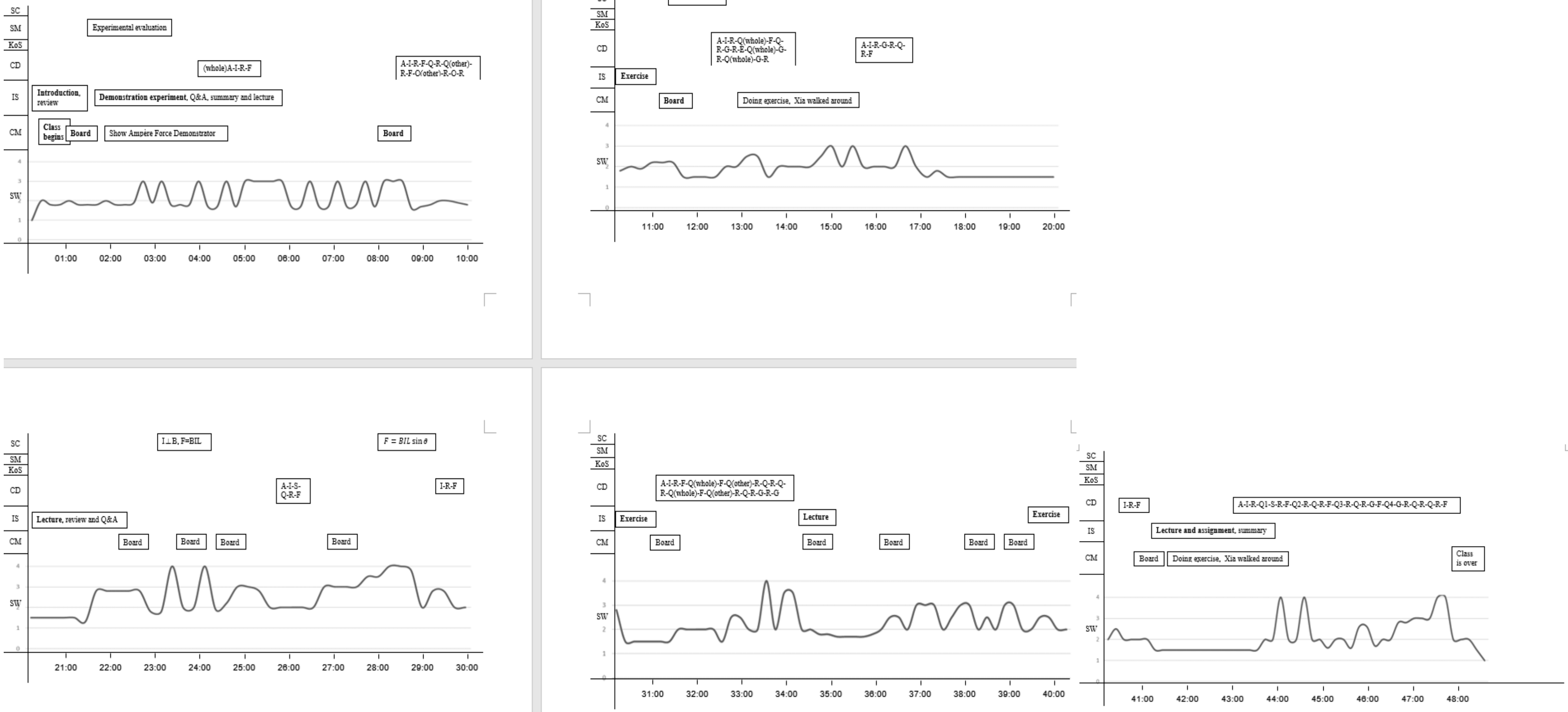


Table 11 E1 Discourse structure

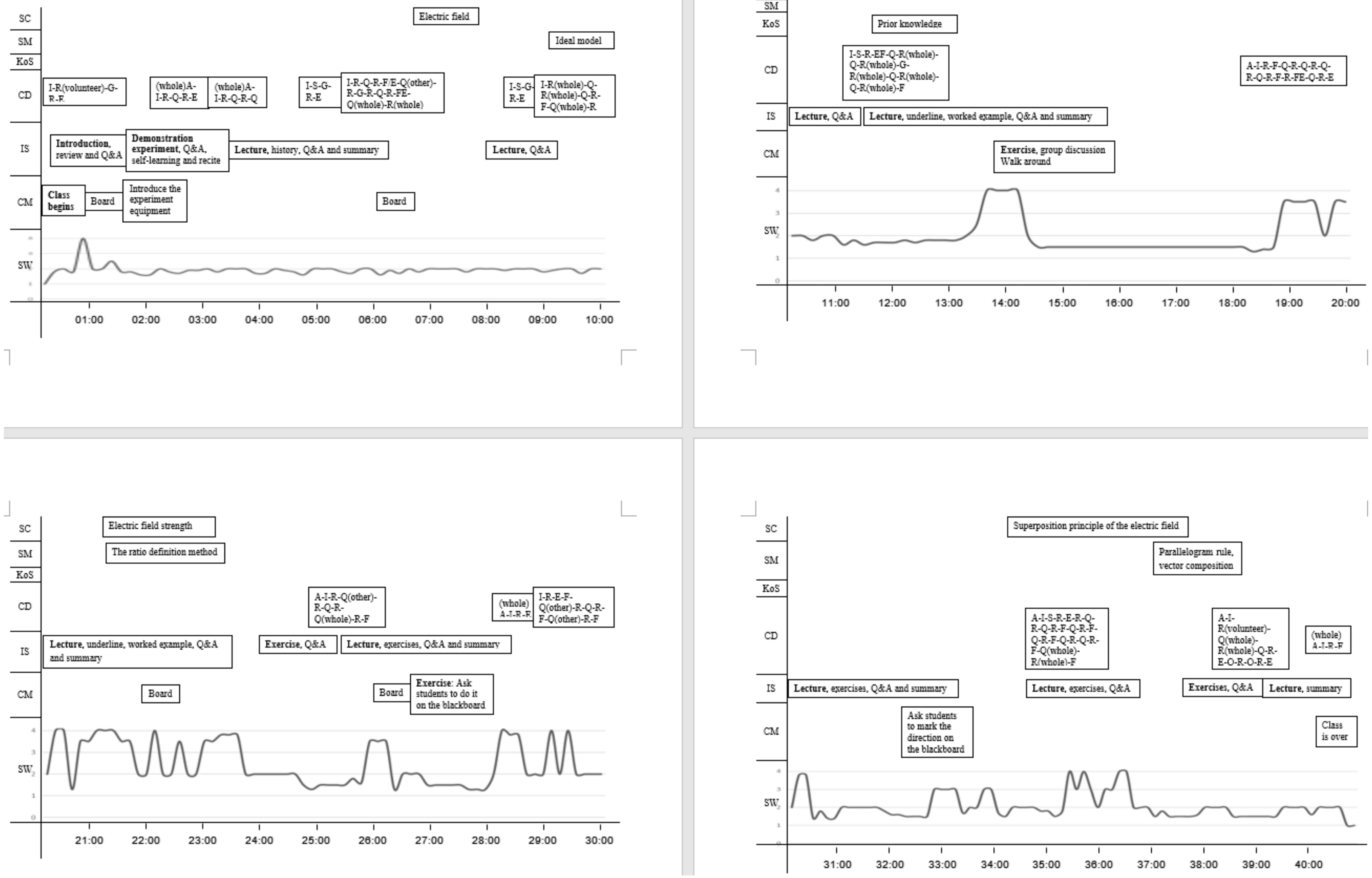


Table 12 E2 Discourse structure

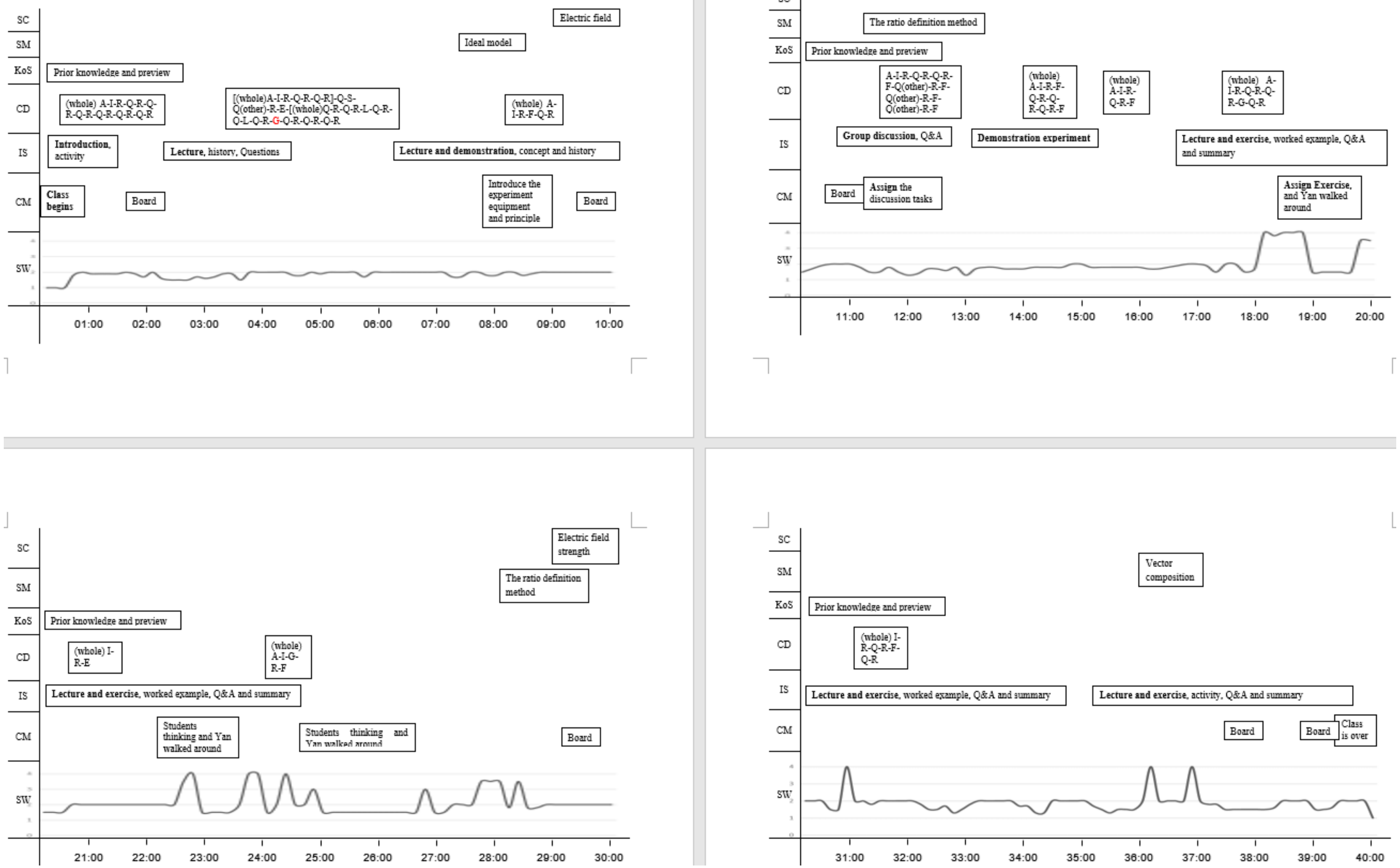


Table 13 E3 Discourse structure

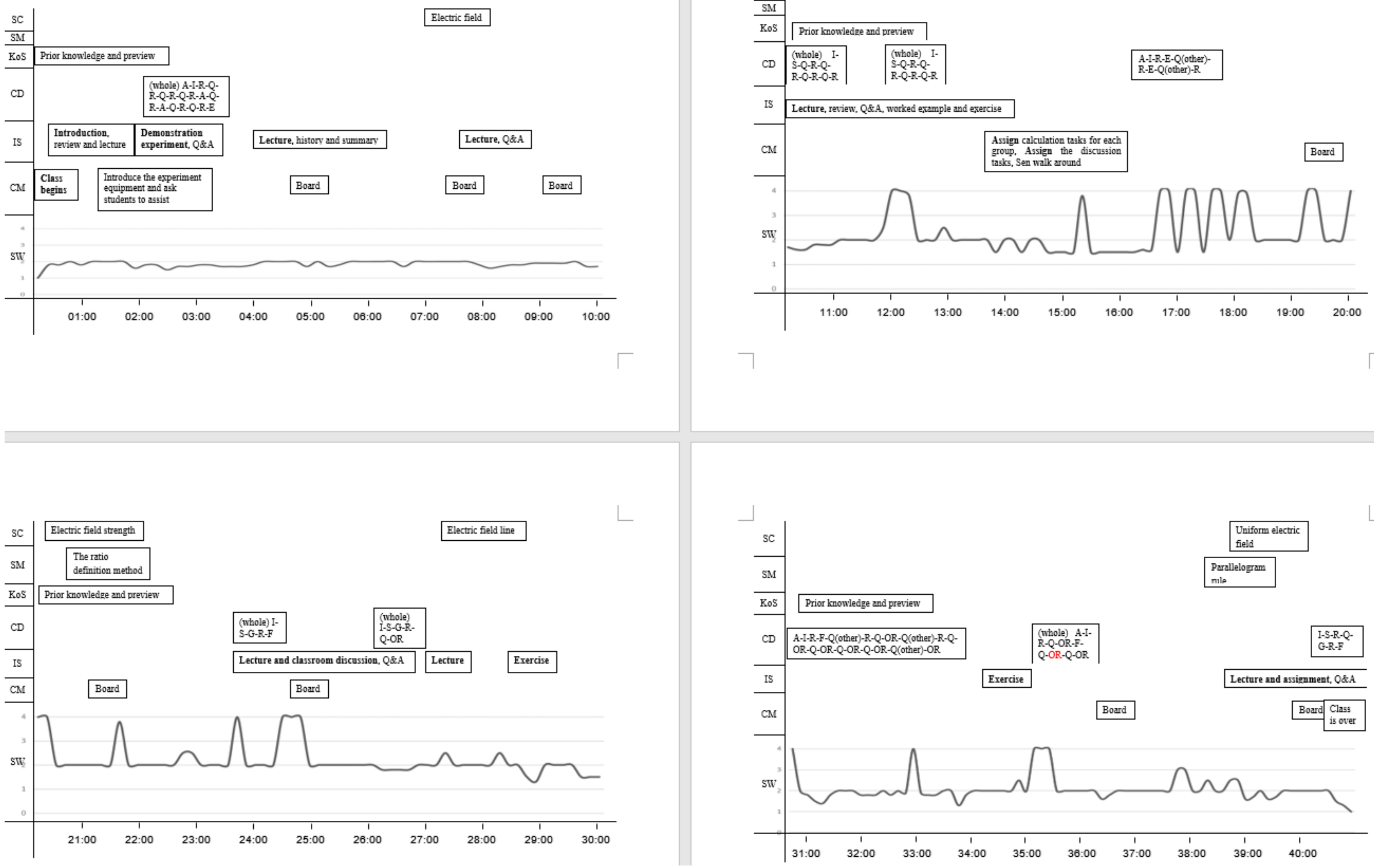


Table 14 E4 Discourse structure

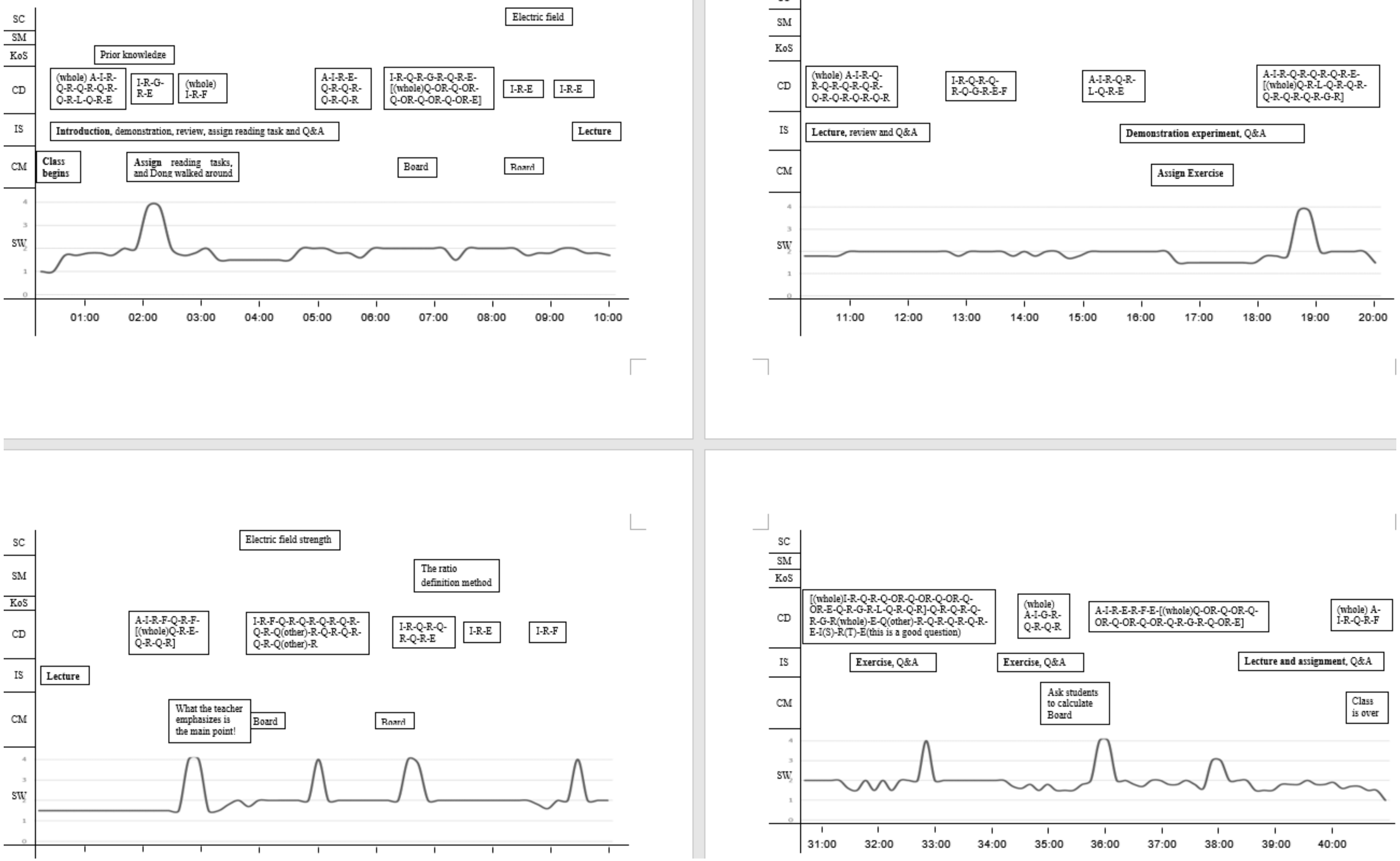


Table 15 E5 Discourse structure

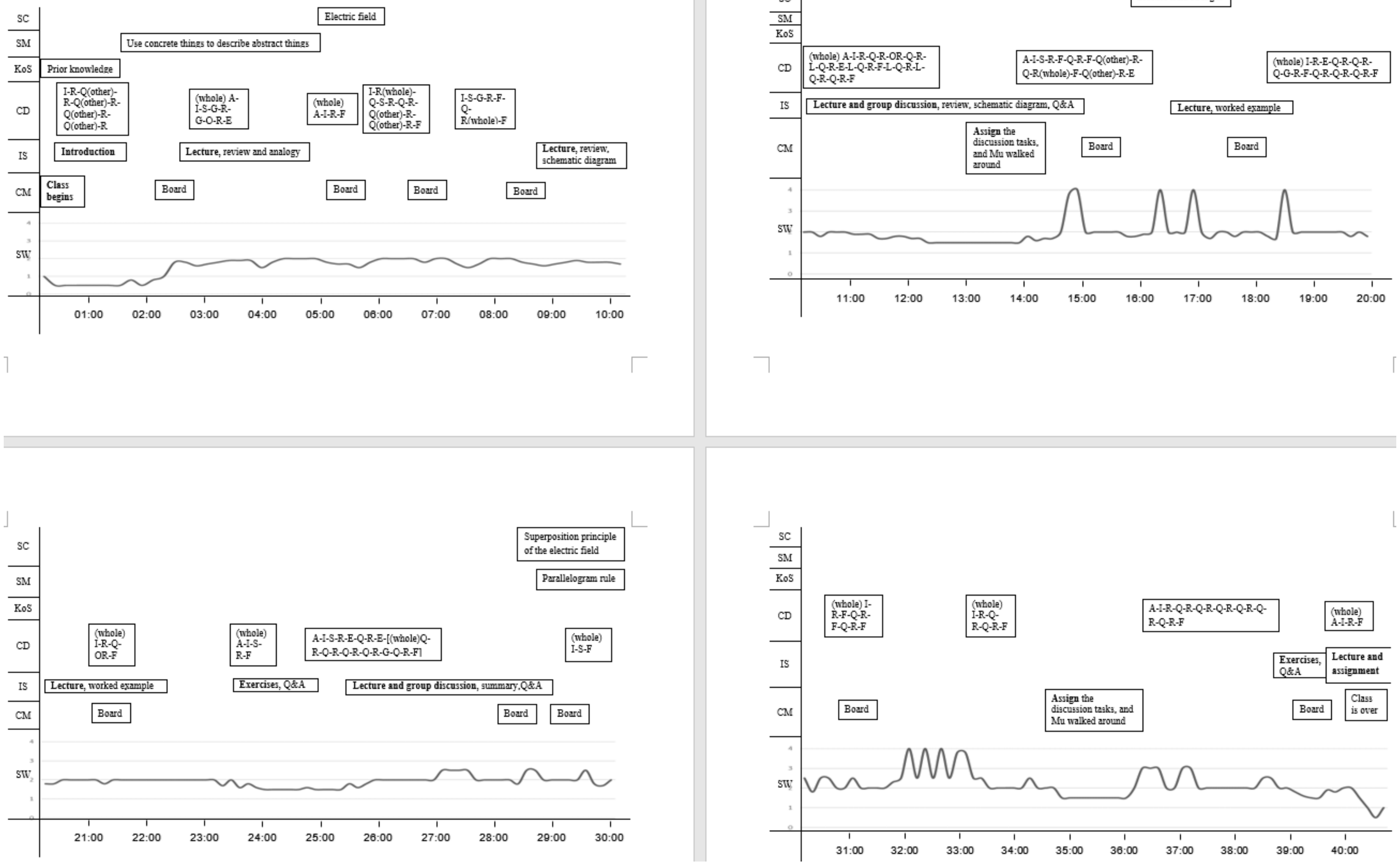


Table 16 E6 Discourse structure

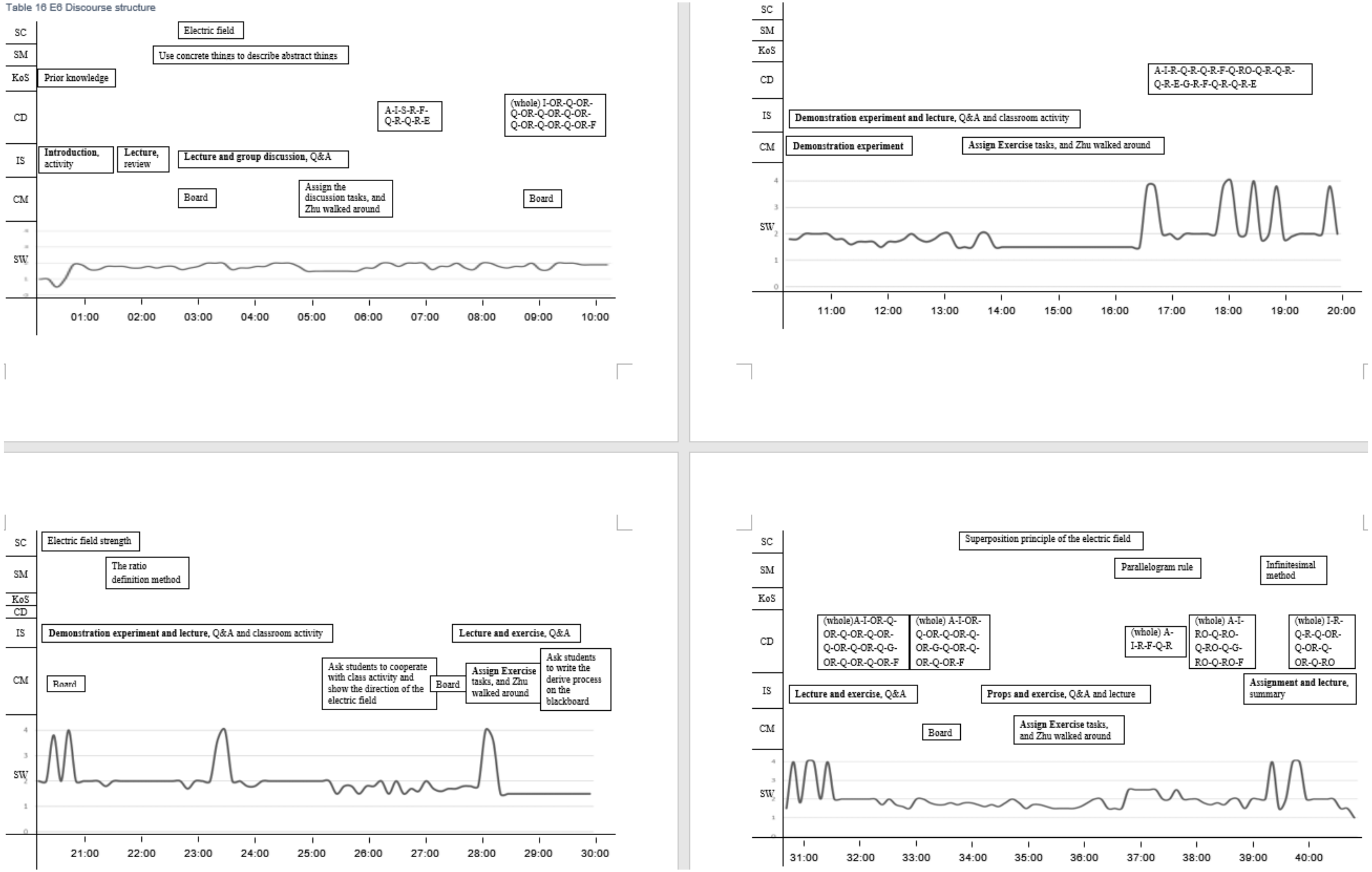
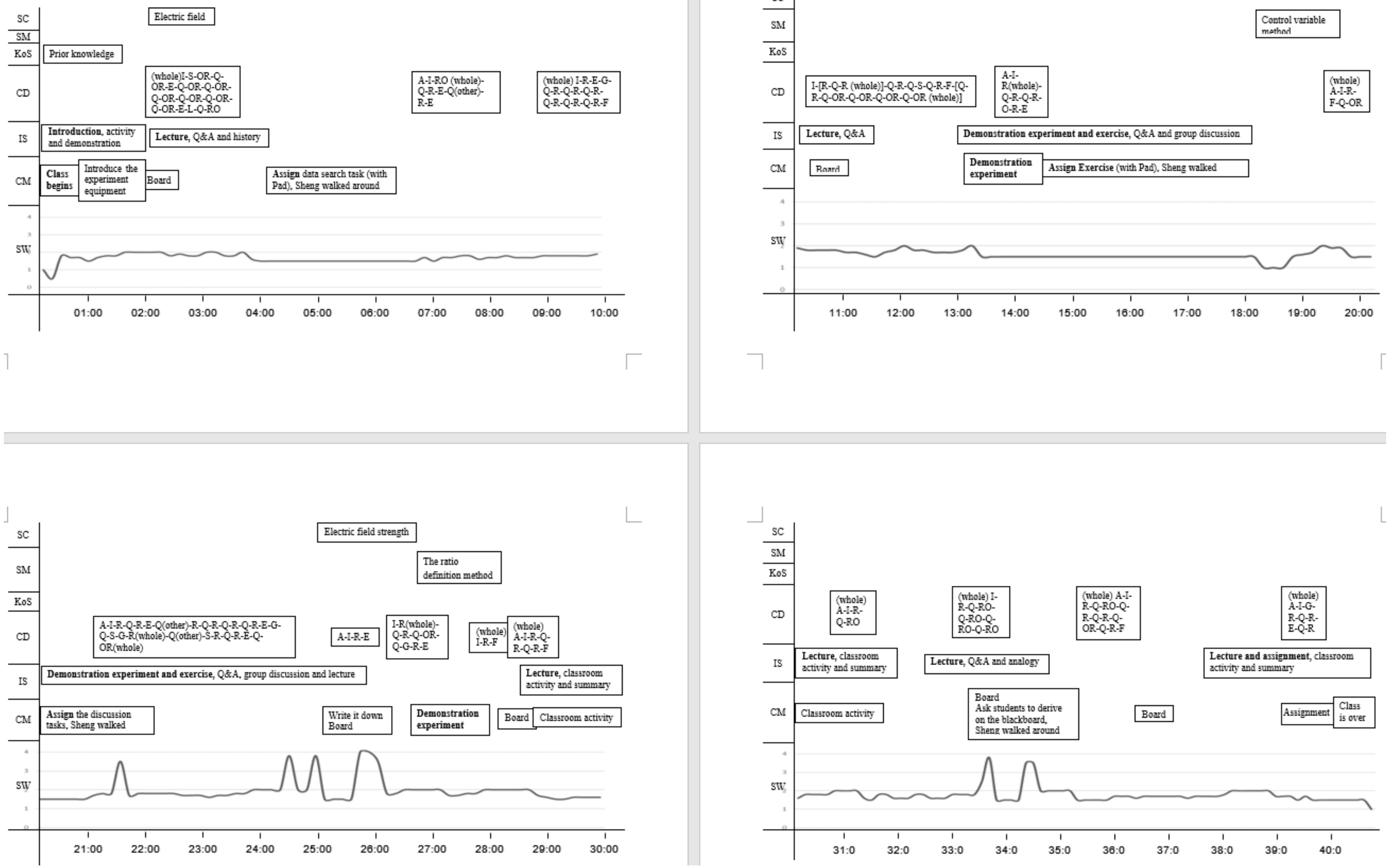


Table 17 E7 Discourse structure



Appendix 6: Examples of six reasoning styles presented in the textbooks

Versions of textbook	Topics	Scientific reasoning styles	Text samples	The way pf presentation (Explicit/Implicit)
CLT	M	E: to evaluate the direction of the magnetic field;	This matter cannot be seen or touched, and we call it a magnetic field. In physics, substantial matter that cannot be seen or touched can be known by its action on other objects. Something like a magnetic field, we can sense it experimentally, so it is a real existing matter. (Peng, 2013, p120)	Explicit
		E and HM: to verify the current generating magnetic field;	For a long time in history, it was thought that electrical and magnetic phenomena were unrelated. By the beginning of the 19th century, some philosophers and scientists realised that various natural phenomena should be related to each other. Based on this idea, the Danish physicist Oersted for a long time with *experiment*s to find this connection, after countless failures, in 1820, in a classroom experiment, Oersted finally found: when the wire through the current, the magnetic needle under it deflected. This discovery made Oersted extremely excited. He continued to do numerous experiments with great interest, and finally confirmed the existence of a magnetic field around the current, and became the first one who found connection between electricity and magnetism in the world. (Peng, 2013, p124)	Explicit and implicit
		C and HM: to introduce the Ampère's rule;	The experimental results show that the magnetic field outside the energised solenoid is the same as that of the bar magnet… After the discovery of a physical law, if we can express it in a clever way, it will be convenient to remember it, and it will be convenient for us to find the connection between quantities. The relationship between the polarity of a solenoid and the direction of current can be described by the Ampère rule. (Peng, 2013, p127)	Explicit and implicit
	F	E: to evaluate the force on the current-carrying wire and coil in a magnetic field	*Experiments* have shown that an energised wire in a magnetic field appears to be subject to forces. The direction of the force is correlated with the direction of the current and the direction of the magnetic induction line. When the direction of the current or the direction of the magnetic induction line becomes opposite, the direction of the energising wire force also becomes opposite. (Peng, 2013, p133)	Explicit
CUT	M	HB and C: to comb the magnetic phenomena;	In the Spring-Autumn and Warring States Periods, some works already have records and descriptions of magnets in our country. The Eastern Han scholar Wang Chong's	Implicit

		'Sinan' described in 'On Balance' is widely recognised as the earliest magnetic orientation tool. The compass is one of the four great inventions in ancient China. At the beginning of the 12th century, our country had a clear record of the compass used for navigation. The main component of the earliest found natural magnet is Fe_3O_4. The magnets now in use are mostly made of iron, cobalt, nickel and other metals or some oxides. Both natural magnets and artificial magnets are called permanent magnets, and they can attract iron objects, and we call this property magnetism. Each part of the magnet has a different magnetic strength, and the strongest magnetic region is called the pole. A freely rotating magnet, such as a suspended magnetic needle, with its magnetic pole point to South at rest is called the South Pole, also known as the S Pole; with its magnetic pole that points to the north is called the North Pole, also called the N Pole. (Zhang, 2007, p80)	
F	E: to explore the direction of Ampère force;	Demonstration Perform the experiment as shown in Figure 3.1-3. 1. Exchange the position of the magnetic pole up and down to shift the direction of the magnetic field, and observe whether the direction of the force changes. 2. Change the direction of the current in the wire and observe whether the direction of the force changes. Through the analysis of these two cases, we have actually understood the relationship between the direction of the force, magnetic field, and the current. Can you express this relationship in a concise way? (Zhang, 2007, p91)	Explicit

	M: to deduce the equation of Ampère force	We learned in Section 2 that a wire of length L placed perpendicular to magnetic field B (Fig. 3.4-4a) is subject to an Ampère force F when the current passing through is I
		$F = ILB$ (1)
		When the direction of magnetic induction B is parallel to the direction of the wire, the force on the wire is zero.
		When the direction of magnetic induction B is at a θ Angle to the direction of the wire (Figure 3.4-4b), it can be decomposed into components $B_\perp$, which is perpendicular to the wire, and $B_{//}$, which is parallel to the wire (Figure 3.4-4c).
		$B_\perp = B\sin\theta$
		$B_{//} = B\cos\theta$
			Implicit

			Where $B_{//}$ does not produce an Ampère force, the Ampère force exerts on the wire is only generated by $B_{\perp}$, and thus obtained F = ILBsin θ (2) This is the expression for the Ampère force in general. (Zhang, 2007, p92)	
	E	M, HM and E: to explore and deduce the equation of electric field strength;	... The force F exerted on the test charge at a point in the electric field is likely to be proportional to the test charge q: F = Eq (1) E is a constant of proportionality and independent of the test charge q. The experiment shows that our conjecture is correct: the force exerted on the test charge at a certain position in the electric field is indeed proportional to the amount of charge in the test charge. The experiment also shows that in different positions of the electric field, the proportionality constant E in formula (1) is typically different, which reflects the property of the electric field at this point, called electric field strength. We learn according to formula (1): $E = \frac{F}{q}$ (Zhang, 2007, p11)	Explicit and Implicit
		HM: to set up an ideal model - test charge;	The charged ball in the experiment is used to test whether the electric field exists and its strong and weak distribution, which is called trial charge, or test charge. The amount and magnitude of the charge must be sufficiently small to have no obvious effect on the charge distribution on the metal ball O, so that the original electric field does not alter significantly due to the appearance of test charge. The analysis here is a conjecture and hypothesis, and its correctness needs to be tested by experiment. (Zhang, 2007, p10-11)	Explicit
AQA	M	HB: to introduce magnetism	Magnetism is a topic with a long scientific history stretching back thousands of years when lodestone was used by explorers as a navigational aid. Scientific research over the past 50 years or so has led to many applications such as particle accelerators, powerful microwave transmuters, magnetic discs and tape, superconducting magnets, and magnetic resonance scanners. Magnetism is a valuable scientific tool used by archaeologists, astronomers, and geologists. In short. magnetism has always been a fascinating topic and continues to be so. (Breithaupt, 2015, p395)	Explicit

F	E and M: to evaluate the force on the current-carrying wire and coil in a magnetic field	The tests above show that the force F on the wire is proportional to: 1 the current I, 2 the length l of the wire. The magnetic flux density B of the magnetic field, sometimes referred to as the strength of the magnetic field, is defined as the force per unit length per unit current on a current-carrying conductor at right angles to the magnetic field lines. Therefore, for a wire of length l carrying a current I in a uniform magnetic current-carrying wire in a magnetic field field B at 90 ° to the field lines, the force F on the wire is given by F = BIl	Implicit
	HM: to explore the principle of electric motor	Consider a rectangular current-carrying coil in a uniform horizontal magnetic field, as shown in Figure 6. The coil has *n* turns of wire and can rotate about a vertical axis. • The long sides of the coil arc vertical. Each wire down each long side experiences a force BIl where I is the length of each long side. Each long side therefore experiences a horizontal force F = (BIl)n in opposite directions at right angles to the field lines. • The pair of forces acting on the long sides form a couple as the forces are not directed along the same line. The torque of the couple = Fd, where d is the perpendicular distance between the line of action of the forces on each side. See Topic 24.4. lf the plane of the coil is at angle α to the field lines, then d = wcosα where w is the width of the coil. • Therefore, the torque= Fwcosα = BIlnwcosα= BIAncosα, where the coil area A=lw. If α= 0 (i. e., the coil is parallel to the field), the torque= BIAn as cos0 = 1. • If α = 90° (i.e., the coil is perpendicular to the fie d), the torque = 0 as cos 90° = 0.	Implicit
E	M: to measure the electric field strength	A charged object in an electric field experiences a force due to the field. Provided the object's size and charge are both sufficiently small, the object may be used as a 'test' charge to measure the strength of the field at any position in the field. The electric field strength, E, at a point in the field is defined as the force per unit charge on a positive test charge placed at that point .	Implicit

	The unit of E is the newton per coulomb (NC^{-1}). If a positive test charge Q at a certain point in an electric field is acted on by force F due to the electric field , the electric field strength E at that point is given by the equation $$E = \frac{F}{q}$$

*M: mathematical deduction, E: experimental evaluation, HM: hypothetical modelling, C: categorisation and classification, P: probabilistic reasoning and HB: historical-based evolutionary (referring to the concept of Kind and Osborne (2017)'s reasoning style).